BREAD

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The Chemistry and Nutrition of Flour and Bread, with an Introduction to their History and Technology

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PREFACE

THE subject of Bread has received much attention during recent years and a great deal has been written on it. We are not, however, aware that there has yet appeared a book which claims to cover in objective and concise fashion the whole matter—historical, theoretical and practical.

We offer three reasons for attempting to repair this omission. (i) Bread is by far our most important food. (ii) In the last twenty-five years our knowledge of the chemistry and nutritional value of wheat, flour and bread has advanced very markedly. (iii) Both the social and political significance of bread have been recognised as they had not previously, largely as the result of the impact of two world wars on the nation's food. Incidentally, we have confined the book to a study of wheaten bread, the bread eaten by the great majority of the people of this country.

Our own *apologia* for authorship is that we have ourselves taken part in the discussions, academic, industrial and political, on the many problems concerning flour and bread which have arisen both during and since the last war. Our close touch with these problems has been preserved by our position as advisers to the British milling industry on nutritional matters.

We do not feel that any excuse is needed for the subjects of Chapters One, Two and Four—the history of bread, the source of our wheats, and the techniques of milling and baking—because they, no less than the relation of bread to nutrition and health, are of considerable interest. They could indeed have been developed much further but for the need to preserve balance in a book of this small size.

We have devoted much of this book to the chemistry of wheat and flour and the factors involved in the milling of wheat. We have done so because flour is the raw material

of bread—in fact, it accounts for over 98% of the solids in bread—and because the quality of a sample of flour depends upon the quality of its parent wheat and the method of milling.

The present work is clearly not to be regarded as a bibliography: the literature is too vast to make it so. Furthermore, much of the published material lacks a high order of objectivity, tending to be influenced by a particular point of view. Not only trade interests have determined this tendency; some scientists cannot escape the same criticism. Here, we have concentrated upon the more concrete advances made in bread research so as to make the book as straightforward and factual a summary as possible.

The book is not intended primarily for the specialist research worker; nor, on the other hand, has it been written for "the man in the street". Although both may find it of interest to them, we have had in mind mainly that section of the public which possesses a scientific background—a section which includes the doctor, the science teacher, the social worker and the dietician.

As we have said, our knowledge of the nutritive value of flour and bread has grown immeasurably in recent years. The attitude of Ministers of the Crown towards the quality of our bread has moved in step with this advance in knowledge. During the last War, the decisions of the Minister of Food on bread were always taken with due heed to the best scientific advice and preceded by exacting trials and, where necessary, by research. Recently, when the sale of white bread was again permitted, the Government insisted that it should be enriched with vitamin B_1, nicotinic acid and iron, in which otherwise it might be deficient. Again, on the question of bread improvers, the Government is awaiting the results of research before deciding on the suitability of the various possible methods.

We are grateful to several of our colleagues for their help, notably to Dr. J. H. Green, who has given invaluable

assistance in the preparation of Chapter Six, and Dr. E. J. Hamley, of the Middlesex Hospital Medical School, and to Dr. C. R. Jones, Dr. J. Pace, Dr. P. Halton and Mr. E. N. Greer of the Cereals Research Station, St. Albans. For the preparation of the figures and diagrams we are indebted to Mr. E. E. McDermott. We owe a special debt of gratitude to Mr. G. H. Brown, who has had the temerity to collect, edit and co-ordinate our separate contributions. Without his persistence the book would never have been completed.

HORDER
E. C. DODDS
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January 1954

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ILLUSTRATIONS

CHAPTER ONE

THE HISTORY OF BREAD

AT the beginning of a book dealing with the importance of bread to man a short account of its history is not out of place, if only because bread has suffered from a surprising lack of attention by scholars. General historical works largely ignore it and the few specialised studies that have been made tend to be speculative. Academic studies of the history of wheat and of milling are available, however, and provide clues to the history of bread itself.

The bread-wheats, of which *Triticum vulgare* is now the best known, probably originated in Persia and spread from there to Europe and to China and India. They were preceded in Europe by the emmer wheats, from which they descended, and by einkorn, the progenitor of emmer. All three main groups of wheat were cultivated at one and the same time in different parts of Europe, North Africa and the Middle East, but as man came to rely increasingly on bread as a staple food, the bread-wheats tended to take the place of emmer and einkorn, and of other cereals such as barley, as a staple crop.

The importance of wheat to prehistoric man clearly depended on the efficiency with which he was able to reduce it to an edible form. Archæological discoveries indicate that the earliest "milling" implements, dating back perhaps some 75,000 years, consisted merely of stones—cup-shaped stones to hold the grain and round stones to pound it. Pestles and mortars, which were used for many purposes, followed later. At some stage in history, stones were first employed for rubbing or grinding the grain instead of pounding it, and as centuries passed the grinding implements underwent considerable improvement. It was found that roller-shaped stones were the best for grinding and that saddle-shaped stones made the best platform for the grain, the "miller" kneeling in front of the latter as he worked

the grinding-stone to and fro. In time, the grinding-stone was fitted with handles and adapted to act as a hopper for the grain; and grooves, similar to those on later millstones, were cut on the saddle-stone. The Greeks mounted the whole contrivance on a table and worked the grinding-stone by means of a lever.

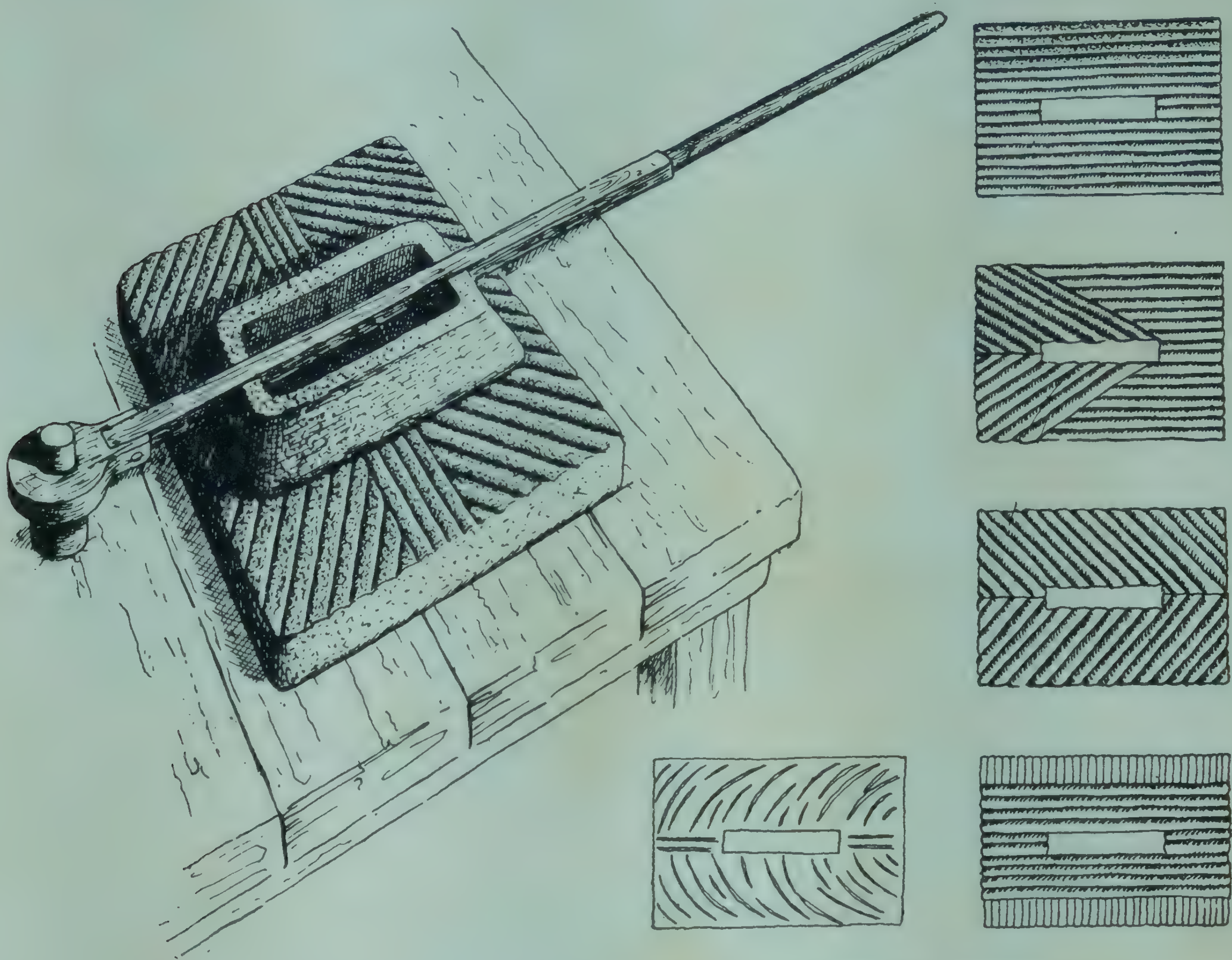

FIG. 1.—Primitive lever mill, showing alternative patterns of grooving.

Such was the technical progress made in milling before, roughly, the second century B.C. Little is known of the methods by which the flour produced by the earliest implements was converted into food; it is believed, however, that cereals were first eaten, in prehistoric times, as porridge or as hard, unleavened cakes. The discovery of fermentation is attributed to the Egyptians, who by the year 2600 B.C. were making bread by methods essentially similar to those followed today. Flour, ground on saddle-stones, was sifted through sieves made from papyrus, mixed with water and

brewer's yeast, and finally baked in jars which had been heated beforehand. Baking was a distinct, if lowly, occupation in ancient Egypt, but bread played a notable part in the country's economy, since it was used in payment of wages.

The Hebrews, the Greeks and the Romans also made bread a staple article of diet. The last-named, whose requirements obliged them to import wheat on a large scale from other Mediterranean lands, were, in the second century B.C., the first to develop a principle overshadowing all previous events in the history of milling, namely, the application of rotary motion to grinding. This involved grinding the grain between two circular stones, the one rotating and the other stationary. Whether large "hour-glass" mills turned by animals or teams of slaves, of the type to be seen in the ruins of Pompeii, or the smaller portable querns turned by hand, were introduced first, is not known, but in any case both types spread rapidly throughout the Roman Empire.

Once the new principle was established, advances in the method of driving the rotating millstone took place relatively quickly. In the first century B.C. the Roman engineer Vitruvius described, and possibly invented, a water-mill with a vertical water-wheel and gearing to convey the drive at right angles to the millstone. The Roman Empire, however, was already well served by its slave- and animal-mills and by hand-querns, and the new mill did not win favour for another four centuries. Meanwhile, about the same time as the invention of Vitruvius, a second type of water-mill had come into existence and had spread to different parts of the Empire. The water-wheel of this mill was laid horizontally in the stream and the drive passed directly to the millstone above, without intermediate gearing.

Although in Rome, as elsewhere, milling and baking remained primarily domestic operations, the benefits offered both by large-scale milling and the official policy of issuing doles of bread to the populace did much to raise the status of Roman miller-bakers. In the second century A.D. they

were organised as a " College of Pistores " with carefully prescribed rules and regulations. Their skill in judging the suitability for bread of different varieties of wheat and in adjusting the grinding and sifting processes enabled them

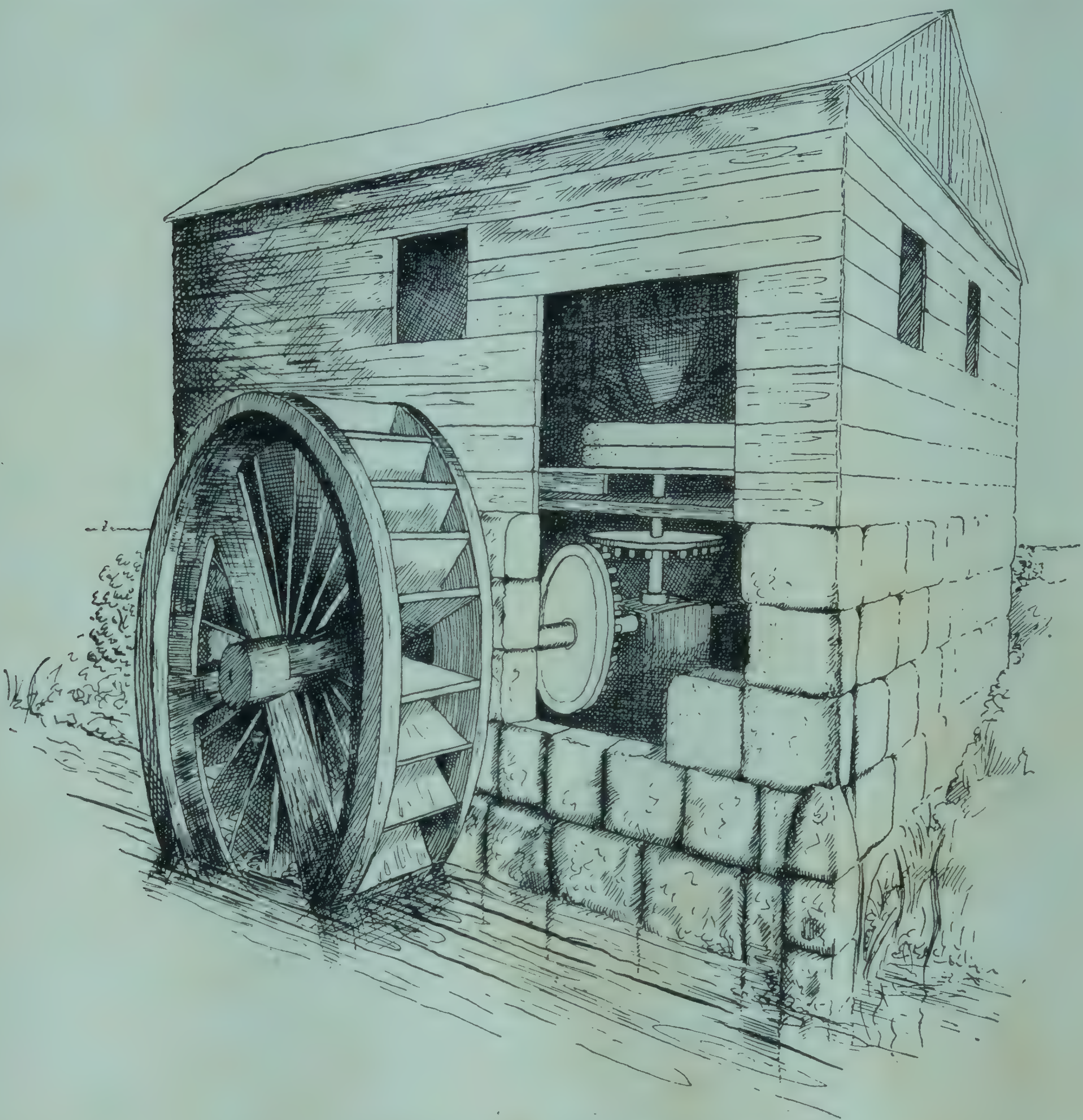

FIG. 2.—Water-mill with vertical wheel.

to produce loaves of many different types and shapes and so satisfy the demands of every rank of society.

Another effect of the improvements in milling achieved by the Romans was to make the bread cereals, in particular soft wheat, spelt wheat, and rye, a new-comer to Europe, more popular at the expense of other cereals. Their cultivation was aided further by the improvements in agriculture

which took place during the Middle Ages. Wheat established itself as the main crop of southern Europe, and rye, which gave better yields on inferior soils, as the main crop of the northern countries, including Britain.

Rotary hand-querns were in use in Britain at the time of the Roman Empire, but water-mills of the Vitruvian pattern did not reach Britain until after the Romans had

FIG. 3.—Water-mill with horizontal wheel.

departed; the first authentic evidence relates to one in a monastery at Dover in 762. They multiplied rapidly, however, in the three centuries that followed, and the Domesday survey of 1081–86 listed over 5,000 in the Midlands and southern England. Water-mills of the direct-drive type were never used in England itself, but they were to be found until the nineteenth century in hilly parts of Scotland, Wales and Ireland, where they had penetrated under Norse influence.

By the end of the twelfth century a new kind of mill,

the windmill, whose origin is obscure, had appeared in England and on the Continent. For seven centuries it partnered rather than rivalled the water-mill, which in fact, in most countries, continued to predominate. The earliest type of windmill was the post-mill, so called because its body was mounted on a post sunk into the ground or secured to a wooden framework. The turret post-mill was similar, with the addition of a turret to house the post and its mounting. A second type, the tower mill, was invented in the fourteenth century and introduced into England in the fifteenth. Unlike the post-mill, whose whole body had to be turned to bring the sails into the wind, only the cap of a tower mill, bearing the sails, required turning, the body itself being fixed.

The rapid increase in the number of water-mills in the ninth, tenth and eleventh centuries was, no doubt, encouraged by the growth of milling "soke" in this period. Its existence made the ownership of mills a profitable source of income to the lord of a manor, because it conferred on him a monopoly of building and operating mills, whatever their motive power, in his manor, and the right to compel his tenants to have their corn ground in his mill (or mills). A statute of 1290, which put an end to the creation of new manors, had the effect of prohibiting new milling sokes in England, but new water-mills and windmills continued to be built by virtue of existing rights. Milling in the home, by hand-querns, although forbidden, probably continued surreptitiously, particularly in manors in which the milling resources were inadequate.

The observance of soke determined the medieval organisation of mills in England. In practice, the manorial lord rented out his mill to a miller, who earned a hard livelihood by keeping a proportion—usually a sixteenth—of the corn brought to him for grinding. As long as soke remained in force, milling necessarily retained its local character; only when soke died out in the late seventeenth and the eighteenth centuries, did the organisation and pattern of English mills alter to any extent.

FIG. 4.—Tower windmill.

In medieval England baking lay outside the miller's province. The great majority of his customers baked the flour that he had ground in their own homes; only in towns did bakers gradually establish themselves. At first, their function was merely to bake flour provided by their customers, but in time they took over the responsibility of providing the flour themselves. In large towns, however, communal ovens were often available for the poor.

Since rye was the predominant crop of medieval England, rye bread was the staple food of the bulk of the labouring class; in times of dearth it was diluted with a flour or meal made from oats, beans, peas and even acorns. In wheat-growing areas wheaten bread or "maslin" bread—the latter made from a mixture of rye and wheat—took its place, and throughout the country as a whole wheaten bread was the food of the more prosperous classes and their dependants. It was chiefly the consumers of this bread who patronised the bakers, and the Assize of Bread, instituted in 1267 to control the price of bread sold publicly and to limit the profit of millers and bakers, was concerned mainly with bread made from wheaten flour. The Assize in effect varied the weight of the loaf according to the price of wheat. It recognised three grades of wheaten loaf, "white", "wheaten" and "household", whose prices were adjusted in the fixed ratio, 2 : 1·5 : 1. The terminology varied through the years; an Elizabethan writer named four kinds of wheaten loaf commonly eaten in his day: "manchet" or "white", "cheat" or "wheaten", "celsus" and "cibarus". The first, the "most excellent" of the four, was a small loaf of well-sifted flour, weighing only 6 oz. The second was a 1-lb. loaf from which much of the bran had been removed; a coarser variety, supplied in noble households where the Assize did not apply, was the "ravalled cheat". Celsus was a whole-wheat bread in "second place of nourishment". Cibarus was a bran loaf, "not only the worst and weakest of all the other sorts, but also appointed in all time for servants, slaves, and the inferior type of people to feed upon".

The records of monastic and noble houses provide evidence that every rank in these establishments was allotted its particular quality (and quantity) of bread, and it was not until the middle of the eighteenth century that what might be termed the "social" classification of bread began to disappear and white bread began to be included in the diet of all classes. The change, which was not complete until the end of the nineteenth century, was due to a number of factors: the replacement, thanks to improved methods of cultivation, of rye by wheat as the country's largest grain crop; an amendment in 1758 to the Assize regulations, which increased bakers' profits on white bread; the abolition of the Assize, in London in 1820 and in the provinces fourteen years later; and the growth of the market for "wheatfeed"—the by-products or residue of the grain after milling—which made the milling of white flour more attractive to millers and in turn promoted the sale of white bread—so much so that in 1865 its price, for the first time, dropped below that of brown bread.

The nineteenth century witnessed changes in the technical processes and in the economics of milling and baking no less fundamental than those that had occurred some two thousand years earlier. The impact of the Industrial Revolution, however, was delayed, and improvements to watermills and windmills which had been introduced, particularly in the United States, were adopted only slowly by English and Continental millers. A steam mill was run successfully in London for five years, but was not replaced after its destruction by fire in 1791. English millers, now emancipated from soke, tended to amalgamate in certain localities and to site their mills at points convenient for water and rail transport. They now themselves bought the grain for their mills—an increasing proportion of which was imported—and sold the flour to the public and to bakers. But the capacity of their mills was for long equal to the requirements of the growing urban population, and there was therefore little incentive to modify the existing mills or build new ones.

It was only after the first quarter of the nineteenth century that English milling capacity was found to be inadequate and imports of flour from the United States and the Balkan countries became necessary. About this time a most important development, destined to revolutionise milling practice, took place on the Continent. In 1834 a Swiss mill made the experiment of grinding wheat between rollers which were driven by steam power. The method was developed successfully in Hungarian mills during the next three decades, and was adopted on a large scale by millers in the United States in the '70's and '80's.

From the bread-making standpoint the flour produced by these new roller mills was superior in every respect to stone-milled flour. Moreover, only roller mills were capable of milling satisfactorily the hard wheats grown in the Danube basin, on the Russian steppes and on the North American prairies, which were forming an increasing proportion of the world's production. The modern mills of the exporting countries were thus in a position not merely to supply England's deficit of flour but also to threaten the existence of English millers unless they followed suit. The more progressive English millers introduced rollers as early as their American rivals, and the industry as a whole did not lag far behind: in the thirty years 1880–1910 three-quarters of the country's water-mills and windmills were pulled down and the remainder converted into relatively large, highly mechanised roller mills, for the most part conveniently sited at ports or on waterways. By 1905 the proportion of wheat imported as flour, which had amounted to 20–25% in the '80's, had fallen to 10%, and by the outbreak of the First World War imports of flour had virtually ceased. Flour-milling capacity in England is still ample for the country's requirements and from this point of view there is no need to import flour. Wheat must be imported since home supplies can satisfy only about 25% of requirements and there is, in any case, a limit to the amount of home-grown wheat that can be included in the present-day bread-making grist.

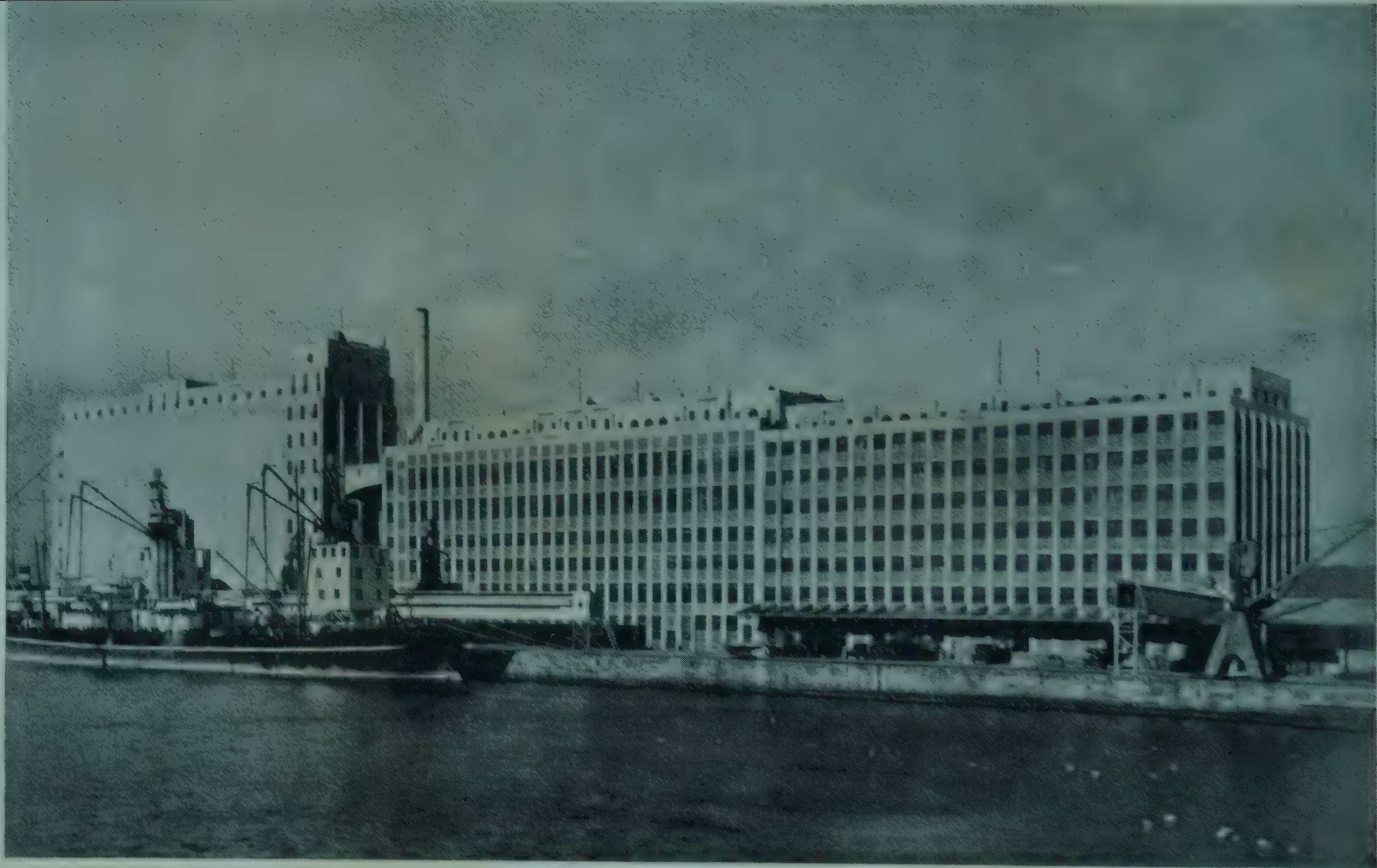

Fig. 5.—A modern flour-mill.

Like the millers, English bakers remained for long substantially unaffected by the Industrial Revolution. A "perpetual oven", with an endless belt to convey the loaves through it, was introduced into the Royal Navy in 1810, and mechanical dough-mixers were invented towards the end of the nineteenth century. However, a large section of the population—a majority in some areas—continued to bake its own bread, and the bakers supplying the rest of the public remained, for the most part, in a small way of business. It was not until the twentieth century, with the advent of motor transport and the application of machinery to all stages of baking, that large-scale or "plant" bakeries were built. At present these supply about half of the bread consumed.

The nutritional value of bread—the aspect which now perhaps overshadows all others—was not widely discussed until the present century, after the discoveries of Eijkman (1890), Hopkins (1912) and others that foods were not only a source of energy and composed of fat, protein and carbohydrate but that they also contained traces of certain substances essential for health. These substances, now known as vitamins, are not evenly distributed throughout the wheat grain, but tend to be concentrated in the germ and branny layers and thus are present in greatest amount in wholemeal and certain brown breads. From this arose the controversy of brown versus white bread which has been the subject of much argument, considerable emotion and, generally, too little research during the last quarter of a century. It is this controversy which, directly or indirectly, takes up much of the later chapters of this book.

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CHAPTER TWO

THE WHEATS OF THE WORLD

JUDGED by the quantity grown, wheat is now the most important of the world's cereals (see Table 1). It has also

TABLE 1

World Production of Cereals

(In million metric tons)

	Average, 1934–38.	1951.	1952.
Wheat	152·7	173·6	196·1
Oats	63·5	60·1	59·9
Barley	49·0	55·2	58·9
Maize	112·8	131·2	140·0
Rye	42·4	41·4	39·7
Rice	139·5	150·6	159·2

the widest range of cultivation, extending from the equator to the arctic circle, at altitudes ranging from sea-level to 10,000 ft. or more. Nevertheless, although its adaptability makes it suitable for cultivation in varying conditions of climate and soil, it can be grown to economic advantage only in fairly dry temperate regions. These regions are by no means restricted in size, for they include the vast territories of the North American prairies, the Argentine Pampas and the Russian steppes. Here are to be found the seasonal variations of climate necessary for the cultivation of first-class wheat—growing seasons that are cool but not cold and ripening seasons that are warm and sunny, the two together lasting for at least ninety days. Here also is to be found a sufficient annual rainfall, from 10 to 30 in., so distributed through the year that the growing season is relatively wet and the ripening season relatively dry. Finally, these areas have the best soils—fine light clays and clay-like loams of close texture, rich in humus, providing

adequate moisture, nourishment and warmth for the growing wheat.

On climatic conditions depends whether the wheat is sown in the autumn, to lie without tillering during the winter months until stimulated into growth by the showers and sunshine of spring, or whether sowing itself must await the spring. Where the soil does not freeze to any appreciable depth, either because it has a protective covering of snow or because the winter is mild, "winter wheats" are normally grown; where, however, the soil becomes frozen to a depth of several inches in the winter, autumn sowing is impracticable and "spring wheats" only are cultivated. They are also grown in relatively arid regions where the period of growth follows a short rainy season and is itself limited.

There are many kinds of wheat, each with its distinguishing characteristics of morphology and appearance, its special requirements during cultivation, and its particular suitability for milling and for baking or processing into bread and other foods. Generally speaking, however, the characteristics of the wheat of any one country tend to become distinctive, and for this reason wheats are known primarily by their countries of origin.

Pride of place among the wheats of the world is taken by Canadian wheat. Not only have Canada's consistently large exports in the present century made it the most familiar to millers in importing countries, but for quality generally it stands second to none, thanks to the ideal conditions of climate and soil found in the prairie provinces of Alberta, Saskatchewan and Manitoba, which grow 98% of the Dominion's crop. The severity of the winter on the prairies precludes autumn sowing, which is confined to the provinces to the east and to the west, but the relatively hot summer, with its high rainfall of the early months diminishing as the crop ripens, is admirably suited to spring wheat sown in April and harvested four or five months later.

The bulk of Canadian wheat is known by the name of Manitoba, a collective title for most of the common varieties

grown in the Dominion. These are hard * red wheats with small, plump, vitreous grains of excellent milling and baking qualities. In British mills, which normally receive about half of Canada's exports, Manitoba provides an almost indispensable part of most of the wheat grists milled. All Canadian wheat, before export, is officially graded according to its quality and freedom from impurities, the main grades being Numbers 1 to 4 " Manitoba Northern ". Separate categories are reserved for Garnet, a variety with unusual characteristics, and for Durum, a different botanical species of wheat. Durum, it may here be observed, is also grown in the United States, in India and on the Mediterranean coast. It is renowned for its ability to withstand drought, and its long, tough grains are particularly suitable for the manufacture of macaroni, and, if carefully " conditioned " and blended, suitable also for inclusion in bread grists.

Second to Canadian wheats are the wheats of the United States, Europe's chief supplier and the largest producer of wheat in the world in the years following the Second World War. The diversity of climatic and soil conditions in the United States enables several types to be grown, and of the total crop about a third is spring sown and two-thirds winter sown. Spring sowing predominates in the northern half of the Great Plains which adjoins the Canadian prairies, winter sowing in the southern half and in the Missouri and Mississippi basins and areas to the east of them. Between the two zones and on the Pacific coast lie areas where both spring and winter wheats are raised.

United States wheats are classified officially in four main classes, in addition to two Durum classes and one " mixed-wheat " class; each class is further split into two or three sub-classes and then graded commercially according to bushel weight, moisture content and purity. Wheat of the Hard Red Spring class, which is mostly allocated to home consumption, has small plump grains, similar to Manitoba, and gives a lively granular flour containing a good percentage

* For a definition of " hard " and " soft " wheats, see below, p. 25.

of high-quality gluten. The Hard Red Winter group, the largest and the most frequently exported, rank as strong * wheats; the grains, longer and thinner than Manitoba, give a high yield of flour with a satisfactory gluten content. The Soft Red Winter wheats in comparison are weak in baking quality, but nevertheless stronger than most English varieties. Weaker still are the White wheats cultivated on the Pacific coast: one of the sub-classes in this group, "Hard" White wheat, is strong enough to be included in bread grists but not strong enough to perform the function of a "filler" (a wheat of medium strength, not requiring to be balanced in a grist by wheats above or below the average strength required); the other White sub-classes are of low strength and used to best advantage in self-raising or biscuit flours.

A third country whose wheat exports normally play a big part in international trade is the Argentine. Here, as in the United States, the area of cultivation extends across several degrees of latitude, but the winters are mild, except in the south, and winter sowing, between April and August, is the rule. Plate wheats—as they are known—have small, thin, red grains giving a moderate flour yield, and being of medium strength, make useful fillers. The official classification is by ports of shipment, with subdivisions indicating the degree of hardness and the commercial condition of the grain. Thus the Rosafé class comprises wheat grown in the Santa Fé and Cordoba provinces and shipped from Rosario; Barusso, the strongest of the Plate wheats, consists of wheats of the Barletta and Russo varieties shipped from Bahia Blanca; and Baril, a weaker wheat with plumper and softer grains, is shipped from Buenos Aires.

Australian wheats are normally of equal prominence in world trade to those of the Argentine. Australia's sowing and harvest periods correspond roughly to those of the latter country. Rainfall is the determining factor in setting the ultimate limits of her wheat-growing areas, which are mainly situated in the south-west and south-east, and in a strip across the south of the continent. This wheat,

* For an explanation of "strength", see below, pp. 25, 76.

characterised by plump, white grains, gives a high yield of flour of satisfactory colour but indifferent baking strength; only at its best is it a satisfactory filler in bread flour. It is given the general grading "fair average quality" and is known by the names of the states of its origin. New South Wales is chief among the wheat-growing states, and its wheat is the most dependable for strength. It is generally stronger than Victorian wheat and less variable than South Australian and Western Australian. Queensland wheat, of which little is exported, is also above the average in strength.

The production of the four wheat-growing areas so far described is shown for the years 1934–38 and 1947–51[1] in Table 2.

TABLE 2

Wheat Production

(5-year averages, in million metric tons)

	1934–38.	1947–51.
Canada	7·2	11·5
U.S.A.	19·5	31·8
Argentine	6·6	5·5
Australia	4·2	5·3

Passing from wheats of international repute to wheats whose destination, as a rule, lies no farther afield than the flour-mills of their countries of origin, one may turn first to the wheats of Russia, a country whose wheat production in quantity falls little short of that of the United States. There, as in the United States, immense differences of soil and climate necessitate the cultivation of many types of wheat. The majority are red, and some—among them the progenitors of the North American hard spring and winter wheats—are of good strength and of good milling and baking characteristics; others are subject to marked fluctuations in quality. Autumn sowing, between August and November, is the rule in the south of European Russia, a third of her total acreage; elsewhere and in Asiatic Russia

the harsh winters permit only spring sowing, between March and May.

Similarly in China, where a fairly hard wheat is cultivated, sowing is divided between the two seasons, according to the geographical position of the crop. Less diversity, however, is found in the India-Pakistan peninsula, where wheat-growing is restricted by climatic conditions to certain large tracts of territory, notably the north-west (particularly the Punjab), the strips of land stretching from there eastwards across the northern plains to Bengal and southwards along the Indus valley to Karachi, and the Bombay Deccan. Sowing is possible only in the last three months of the year, and the wheat grown is in general dry and hard, giving a flour of good water absorption.

Two further wheat-growing areas are formed by the countries of northern and western Europe and by the countries of eastern Europe (outside Russia). United Kingdom wheat, considered in some detail below, is typical of the wheats of the former. Eastern European wheats are slightly stronger than Western, although the strong Danubian varieties renowned in the pre-1914 era are no longer grown.

Outside the principal wheat-growing regions mentioned above, wheat is grown in many countries where natural conditions, although often far from ideal, permit the raising of sizable crops. In South America they include Brazil, Chile and Uruguay; on the African continent, French North Africa, the Union of South Africa, Northern and Southern Rhodesia, Kenya and Egypt; and in Asia, Turkey, Syria, Persia and Japan.

United Kingdom Wheat

Wheat grown in Britain possesses the cardinal virtue of giving a high yield of grain to the acre—on the average as high as that of any other country; it suffers from the hazard of bad harvest weather, which can spoil the condition and more especially the quality of the harvested crop. These factors have contributed to the fluctuating fortunes of wheat-growing in Britain during the last hundred years, when the

crop has varied in its contribution to the country's flour supply from about 90% in 1840 to less than 10% in 1930, since when it has risen, being now about 25%. The decline in wheat-growing that occurred at the end of the nineteenth century was due in large part to the competition of imported grain of more reliable condition and quality; to meet this competition those British farmers who continued to grow wheat sought to increase their yield of grain rather than to compete in terms of better quality. As a result, many flour-mills which had previously depended on home-grown wheat as their only raw material ceased to operate, and much of the trade in milling shifted to the ports where better equipped and larger milling units were able to operate almost independently of home supplies. More recently it has become necessary for national reasons, both in war and peace, to reduce imports of wheat as much as possible and to supplement them to the largest extent by home supplies. Consequently, since the possible wheat acreage is limited, it has been even more necessary to strive for maximum yields and to endeavour to secure the highest possible quality in the crop. Scientific enquiry has played a considerable part in the progress that has been made in these directions; the following is a short account of some of its main aspects.

Hybridisation of wheat by cross-pollination is infrequent in nature and, before the re-discovery of Mendel's Laws of Inheritance, wheat-breeding by this means seems rarely to have been practised. Improvement of wheat by selection did, however, result in the establishment of so-called "Land race" varieties, of which one known as Squarehead has subsequently proved of great value in wheat-breeding. The work of Sir Rowland Biffen at Cambridge during the first twenty years of the present century was probably the most outstanding scientific advance in wheat-breeding that has so far occurred. Biffen [1] showed that a large number of the attributes of the wheat-plant, such as height and strength of straw, colour of grain and chaff were governed by Mendelian or genetic factors which could be varied by selection from hybrids produced by cross-pollination. He

showed further that resistance to some diseases, such as yellow rust, was a hereditable factor, and for these purposes made use of foreign wheats to improve the indigenous stock.

As a result of experiments in which he was assisted by the British flour-milling industry,[2, 3] he came to the conclusion that the quality of the protein in the wheat endosperm was itself governed by a genetic factor; and he accordingly made experiments with the object of producing a high-yielding British wheat of a strength sufficient to compete with imported grain. The wheat Yeoman, which he bred for this purpose and which was introduced in 1919, still remains in cultivation and is still looked upon as one of the best bread-making wheats grown in Britain.

The progress due to the practice of hybridisation has not invariably assisted the quality of the British crop; since it has not been subject to the control practised in many countries, it has resulted in the production of a large number of varieties which have been introduced without regard to their value to wheat users. Percival [4] describes more than seventy varieties and does not exhaust the list. In an endeavour to standardise and to improve the types of wheat produced, the National Institute of Agricultural Botany, Cambridge, published in 1943 a Recommended List of wheat varieties which it has since periodically revised.[5] This list, which enumerates some thirty varieties, has been drawn up to summarise and make generally available the experimental information from variety trials. It has thus to take into account the several factors which make for the value of a present-day wheat. In drawing up the list the Institute has collaborated with the Research Association of British Flour Millers, which has carried out the necessary milling and baking trials.[6, 7]

Two current practices—those of high manuring to produce high grain yields, and combine harvesting to cheapen and speed up harvesting—call for short, strong-strawed wheats, resistant to diseases such as rust and eyespot which impoverish the crop and reduce its standing power. Because it is necessary to cut wheat fully ripe when combine

harvesting is employed, it is necessary that the grain should be resistant to premature germination in the ear in wet harvest weather, again a factor of genetic origin [8]; the prime agronomic factor of high yield goes almost without saying. To these may be added the requirements of wheat-users that grain should mill easily and that it should be suitable for baking into one of the different products, such as bread or biscuits, of which flour is the main ingredient.

Of the varities grown at present, a superiority in yield has been shown by winter wheats of the French type, of which Bersée and Hybrid 46 are examples. A similar superiority has been found in spring wheats of Swedish breed, of which the most widely grown is Atle. These have to a large extent replaced the home-bred varieties, such as Yeoman and its later hybrids, which were of bread-making strength, and wheats such as Victor or Little Joss, which were especially suitable for biscuit flour. While the new spring wheats fulfil the requirements both of yield and quality, in their class, the winter wheats are for the most part highly successful as to yield, but are, in milling value, intermediate between the two distinct types (biscuit and bread wheats). The future improvement of the crop would therefore seem to require a renewal of the work begun by Biffen in the reconciliation of wheat yield and wheat quality.

The development of wheat varieties and methods of cultivation and their beneficial effects on yield may be illustrated by the following table, indicating average yields of grain during the past seventy years, which is drawn from Percival [4] and Ministry of Agriculture statistics.

Ten-year period.	Average yield, cwt. grain/acre.
1879–1888	14·9
1889–1898	16·0
1899–1908	16·8
1909–1918	16·7
1919–1928	17·1
1929–1938	17·6
1939–1948	18·9
(1948–1952)	(22·4)
World average 1940–44	7·4

One may compare the recent increases in grain yields with changes in popularity of wheat varieties. Whilst accurate estimates of the relative acreage of the different varieties have never been made, Brett [9] has, in a survey of seed samples received by the Official Seed Testing Station, shown the relative decline of established wheats and the rapid expansion of new varieties. To take an example, the variety Little Joss, first introduced in 1908, comprised, on this basis, 16% of the total wheat crop in 1940 and less than 4% in 1950. Bersée, which was practically unknown in 1940, accounted for more than 12% in 1950. These are no more than two examples selected from several.

The following table lists the British wheat varieties of greatest popularity from the miller's point of view for the manufacture of bread and biscuit flours:

Bread wheats.	Biscuit wheats.
Atle *	Victor
Holdfast	Juliana
Yeoman	Staring
Redman	Little Joss
Warden	Squarehead's Master

* Usually spring sown.

As an appendix, one may cite the allocation of British-grown wheat in flour-milling during recent years. Assuming a total crop of 2,000,000 tons of grain, approximately 1,550,000 tons are used for milling, out of which it is estimated that:

900,000 tons are made into bread flour				
300,000	,,	,,	,,	household flour
350,000	,,	,,	,,	biscuit flour

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CHAPTER THREE

THE CHEMISTRY OF WHEAT, FLOUR AND BREAD

The Structure of the Wheat Grain

A grain of wheat may be lean and slender, characteristic of South American (Plate) wheat, or plump, as in many French- and British-grown varieties, such as Squarehead's Master and Victor. Its weight may vary from 10 mgm. in a shrivelled grain to 70 mgm. in a plump, well-filled grain, with an average weight of about 45 mgm. Wheat is often classified as "hard" or "soft". The former contains a majority of flinty or translucent grains, at once apparent when they are cut across, the latter a majority of starchy and opaque grains. In general, among the bread wheats, hard wheats are strong wheats—i.e., they give bold, upstanding loaves of good texture, in contrast to the small, dense loaves made from weak wheats. Canadian (Manitoba) wheats are outstanding in their strength, whilst most English and Australian wheats are weak. Strength is related not only to the protein content of the wheat—although for many wheats there is a correlation within one variety—but also to the quality of the protein. A precise understanding of this word quality awaits further research. The miller blends his wheats to give a flour acceptable to the baker and his customers. In addition, he is aided by the use of improvers. These are chemicals added to the flour in very small amounts which either modify the flour proteins or influence the pattern of the enzyme reactions taking place during fermentation. They are considered in some detail in Chapter Five.

The wheat grain is the fruit of the wheat plant. As such it is the end of one generation, whilst as seed it is the beginning of the next. The cycle, which should be borne in mind during a discussion of the chemistry of the grain, is illustrated by Figs. 6 and 7, for which we are indebted to

FIG. 6*a*.

FIG. 6*b*.

FIG. 6*c*.

FIG. 6*d*.

Fig. 6*e*.

Fig. 6*f*.

Fig. 6*a*.—Wheat grain before growth.

Fig. 6*b*.—5 or 6 days after the start of germination. The main and two lateral roots are well developed; root hairs have been produced.

Fig. 6*c*.—Two weeks after the start of germination. Two leaves are formed; secondary roots and a further pair of lateral roots are developing.

Fig. 6*d*.—After some weeks of growth. Side shoots, or tillers, have developed.

Fig. 6*e*.—About mid-June in Southern England. The ears on the tillers have just emerged and have still to complete elongation. Flowering is in progress.

Fig. 6*f*.—Ears of an awned or bearded, and of a non-awned or beardless, variety.

Dr. J. J. C. Hinton of the Cereals Research Station, St. Albans. The first stage of germination is reached in a few days, depending on conditions of temperature and moisture. The second stage follows one or two weeks later, but the subsequent formation of tillers, or side shoots formed from buds produced at the base of the main stem, takes place after a variable period. In autumn-sown wheat it is usually not reached until the end of the winter, tiller formation

FIG. 7*a*.—The flower is not quite fully mature. The glumes have been separated to show the three stamens and feathery stigma.

FIG. 7*b*.—About two weeks after fertilisation. The grain is nearly half size. Remains of the stigma are visible.

FIG. 7*c*.—About eight weeks after fertilisation. The fully developed grain still retains the remains of the stigma.

proceeding slowly during the winter period. In spring-sown varieties, or in early sown autumn varieties, it quickly follows the preceding stage. The greater the number of tillers the greater the strength and yield of the plant. The final stage is the elongation of each stem bearing at the apex the flowering ear. This takes place in the period of rapid spring growth of most plants, and flowering is usually in progress by mid-June. Most varieties of wheat are awnless,

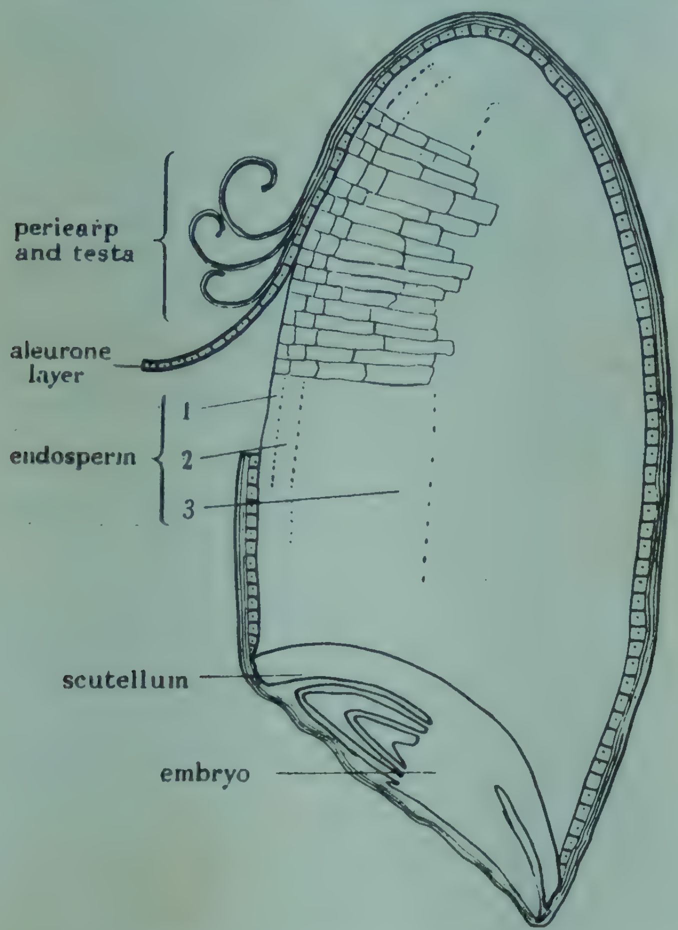

FIG. 8.—Diagrammatic section of a wheat grain.

but there are a few which are awned or bearded, and an ear of such a variety is included in Fig. 6*f*.

A wheat seed consists of the embryo plant and a sufficiency of food to establish it as a seedling. The food—the endosperm—is separate from the embryo, which is situated at one end of the grain. The embryo itself consists of what can conveniently be called the embryo proper, which develops into the shoot and root of the seedling plant, and the scutellum, which does not develop any further. The whole is surrounded by the seed- and fruit-coats, the testa and pericarp. These parts are shown diagrammatically in Fig. 8;

the aleurone layer is a specialised part of the endosperm but differing in form and chemical composition from the remainder of the endosperm. Thus there are five major parts of the grain differing in function and chemical composition. Furthermore, their composition is necessarily influenced by the conditions under which the grain is formed.

If only in view of the varying weight and shape of wheat grains, the proportions of the different parts must also vary. Thus Hinton,[1] in an accurate determination of the percentages by weight of scutellum and embryo in twenty-seven grains of different varieties, found the ranges to be 1·31–1·90 and 0·85–1·53% respectively.

On the other hand, Crewe and Jones [2] found that the average thickness of the pericarp and seed-coat layers in several varieties of wheat was sensibly constant at 67 μ,* that of the aleurone layer being 30–36 μ.

The following figures [3] are given as an approximate guide:

	As % of weight of grain.	
Pericarp :		
Epidermis, Epicarp	4·3	8·0
Endocarp	1·5	
Seed-Coat :		
Testa, Hyaline layer	2·2	
Aleurone layer	6·5	
Germ :		
Scutellum	1·5	
Embryo	1·0	
Endosperm	83·0	

Bran is the collective term used in milling to denote the pericarp, seed-coat and aleurone layer, which, together with a varying but small quantity of attached endosperm, are separated from the flour as distinct pieces or fragments.

The average endosperm content is more often given as

* $1\ \mu = \frac{1}{1000}$ mm.

85% or higher, but Hinton's accurate dissection studies suggest the lower figure of 83%. The endosperm cells vary in size, but follow a distinct pattern. In cross-section those round the dorsal portion of the grain are needle-like, *circa* 200 μ in length and 50 μ in width, whilst the cells in the centre of the cheek are polygonal in shape and approximately 130 μ by 100 μ. Each of these cells is made up of starch granules which vary in size from about 35 μ down to 1–2 μ in diameter, the individual cells being supported by a protein matrix.[4] Hard wheat is easier to mill than soft, since it gives a readier separation of bran from endosperm, and the liberated flour is more mobile and easier to sift. Wheat grown in Britain is largely soft in character and its flour is more fluffy to the touch. Greer and Hinton [5] have shown that the feature which differentiates hard wheats from soft is the way in which, when under slight pressure, the endosperm of hard wheats tends to fracture cleanly along the boundaries of the cell walls.

THE CHEMISTRY OF WHEAT

Factors Affecting its Composition

The chemical composition of wheat is determined primarily by its agricultural and environmental conditions. Thus, other things being equal, the nitrogen content of the soil determines the number of heads that each plant will produce and, during the actual heading period of growth, the nitrogen content of the grain. Experiments on the effects of a spring dressing of nitrogen manure on a large number of plots in Hertfordshire over a period of four years gave the following mean figures [6]:

	No dressing.	Late April dressing.	Late May dressing.
Yield, cwt./acre . . .	23·7	27·7	28·8
Protein content, % .	9·0	9·4	10·8

The vitamin-B_1 content of wheat, although apparently influenced by genetic factors, increases as the protein content rises. For English wheats with a mean protein content of 9·9% the B_1 figure averages 3·3 μgm./gm.; it increases

FIG. 9.—Regular-shaped particles in a hard wheat flour—largely intact endosperm cells. (× 50.)

FIG. 10.—Amorphous soft wheat flour particles, showing disintegration of cell structure. (× 50.)

by about 0·3 μgm./gm. for each 1% rise in protein.[7] There is also a positive correlation between the contents of nicotinic acid [8] and iron [9] and the percentage of protein, whilst amongst the minerals the manganese content is regulated to a large extent by the pH of the soil, increasing in acid soils.

The effect of variety on composition is relatively small. For example, under English conditions the maximum difference in protein content between varieties grown in a constant environment is about 1%, whereas with different environments the range is about 5%. Incidentally wheat is practically entirely self-pollinated, so that constant varieties can be maintained.

The effect of environment explains the marked differences in the average composition of English and Canadian wheats. Careful analyses of Nos. 1 and 2 Manitobas imported in 1943 and an English sample compounded from thirty-two samples covering nineteen varieties grown in different parts of England in the same year, gave the following results: [10]

TABLE 1

Comparison of Canadian and English Wheats

(15% moisture basis)

	%.				μgm./gm.		
	Carbohydrate.	Protein.	Fat.	Fibre.	B_1.	Riboflavin.	Nicotinic acid.
Canadian	63·0	13·6	2·5	2·1	3·5	1·7	55
English	66·8	8·9	2·2	2·1	2·9	1·7	48
	mgm./100 gm.						
	Na.	K.	Ca.	Mg.	Fe.	Cl.	P (total).
Canadian	3·2	312	28	141	3·8	38·5	350
English	3·4	361	35	106	3·0	35·5	340

This comparison is, however, complicated by the facts that the varieties of wheat compared were different and

that the Manitobas were spring sown and the English varieties winter sown. Other experiments have shown that on the same soil spring sowing gives a grain with a protein content some 1·5% higher than that of the same variety sown in winter.

The figure for fibre in Table 1 represents the insoluble residue after treatment of the ground wheat with boiling weak acid and alkali. It is derived from the cellulose and lignin in the outer layers of the grain and to a small degree from the germ and the matrix supporting the individual endosperm cells; it is a purely empirical test, but one of great practical value, in that it indicates the amount of the outer layers in a sample of flour or meal. As a rough measure the fibre % × 8 gives the bran content of a sample of meal.[11]

A factor held by some to reduce the nutritive value of wheat is the use of fertilisers instead of farmyard or organic manure. Ogg and Nicol,[12] however, in 1945 pointed out that wheat grown at Rothamsted in a field treated for over ninety years with complete fertilisers and no manure was the equal of wheat grown on a plot which had received annual dressings of farmyard manure throughout the same period. The vitamin-B_1 contents, moreover, were the same. In 1953 Ogg and Cuthbertson [13] separately affirmed that fertilisers were a necessary supplement to manures, which were inadequate both in quantity and in composition for the needs of agriculture, and repudiated any suggestion that they were harmful to man in their effects.

The Pericarp and Seed-coat Layers

The pericarp and seed-coat layers contain cellulose, hemicelluloses (a range of polysaccharides yielding simple sugars on hydrolysis) and lignin (non-carbohydrate, probably a polymer of phenylpropane and highly resistant to chemical and enzyme action). They also contain small amounts of protein, fat, vitamins and minerals. Thus Hinton [3] found in an English wheat with 8% protein that the protein content of the dissected pericarp and testa calculated on the

N (nitrogen) content averaged 4%, whilst the B_1 content was 0·6 μgm./gm., compared with 3·6 μgm./gm. for the whole grain. It is unlikely, however, that all the N in the pericarp and testa is protein N. The ash content was of the order of 2%, compared with about 1·5% for the whole grain, indicating an appreciable mineral content.

It is, however, more convenient to consider the various nutrients in wheat and their distribution in the grain under their separate headings.

Carbohydrate

The principal constituent of wheat, starch, is confined almost entirely to the endosperm, which contains approximately 75% by weight; based on the weight of the whole grain the starch content is roughly 62%. The starch is present in small granules ranging in diameter from about 1 μ to 35 μ, but over 90% of the granules have a diameter of 15 μ to 35 μ.

Each granule has an envelope, possibly cellulose, which is highly resistant to enzyme attack. During milling, however, a certain proportion of the granules, estimated as the equivalent, on average, of about 10% of the total starch, are mechanically damaged, and these are readily attacked by enzymes.[14] Without this mechanical damage the flour would give badly fermented bread. On the other hand, the damage must be controlled; otherwise the bread will be of poor volume and texture.

The starch complex in wheat is made up of two large molecules, amylopectin and amylose, roughly in the ratio of four to one; both molecules on hydrolysis are broken down to glucose. Amylose is water soluble and gives an intense blue colour with iodine, whereas the amylopectin is less soluble and gives a reddish colour with iodine. In the case of certain varieties of maize and rice—the so-called waxy cereals—the starch is practically pure amylopectin, but waxy wheat has not yet been reported.

Endosperm also contains small amounts of cellulose, which is built up, though in a different way, from a large number

of glucose molecules and of hemi-celluloses. This latter term covers a range of polysaccharides of high molecular weight which are readily broken down into simple sugars on hydrolysis. They include the pentosans, which are based on the pentose sugars, arabinose and xylose. The content of hemi-celluloses in the endosperm is about 5%. Simple sugars, including sucrose, maltose, glucose and fructose, are also present in the endosperm. In the endosperm from normal wheat these sugars total about 1%.[15] Starch is completely absent from the germ, which does, however, contain appreciable amounts, probably about 20%, of water-soluble carbohydrates, chiefly sucrose and raffinose. This accounts for the sweet taste of germ. The content of hemi-celluloses is probably small, the figures for commercial germ reported in the literature being misleading because of the presence of much pericarp.

Protein

Hinton [3] gives the following figures for the protein distribution in wheat (English, Vilmorin 27) with an overall protein content of 8·0% (N × 5·7). As already pointed out, however, the N of the pericarp and testa particularly is probably not wholly due to protein.

TABLE 2

	Protein content, %.	% of total protein in grain supplied by fraction.
Pericarp	2·8	1·7
Testa	9·7	2·3
Aleurone layer	18·0	16·0
Endosperm (outer)	12·5	19·0 } 72
,, (median)	8·0	12·0 } 72
,, (inner)	5·7	41·0 } 72
Embryo	30·4	3·5
Scutellum	24·3	4·5

The gradient in the endosperm is particularly striking, and is reflected in the protein content of flours of different

extraction, which decreases as the rate of extraction is lowered (cf. Table 11).

The outstanding protein of wheat is gluten. When a dough from wheaten flour is washed under a gentle stream of water, most of the starch is removed, and a coherent elastic mass of crude gluten remains. On a dry basis this contains about 87% gliadin and glutenin and 13% non-protein constituents, including about 8% starch, lipoids and phospholipoids.[16]

The classic researches on the proteins of the wheat-grain are those made by Osborne in the early years of the century.[17] This work remains the most comprehensive investigation of the wheat-proteins, and his nomenclature for the different protein fractions is still widely used.

He characterised the proteins as: *gliadin,* insoluble in neutral aqueous solutions but distinguished from all the others by its solubility in neutral 70% aqueous ethanol; *glutenin,* insoluble in neutral aqueous solutions and dilute alcohol but soluble in dilute acid or alkali; an albumin type of protein, *leucosin,* soluble in pure water and coagulated by heating its solution to 50–60° C.; and a globulin similar in properties to many globulins found in other seeds.

The gliadin fraction comprises about 40–50% of the total protein of the grain and the glutenin about 40%; the proteins soluble in water and dilute salt solutions account for most of the remainder.

The soluble proteins are mainly located in the germ and outer layers of the grain, while gliadin and glutenin form the matrix of the endosperm.

Osborne regarded his protein fractions, characterised, as we have noted, by their solubility relations, as individual proteins. Judged by modern criteria of protein homogeneity this view is no longer tenable. In particular, Osborne's view of gluten as predominantly an intermixture of the two "individual" proteins, gliadin and glutenin, must now be regarded as an over-simplification.

All modern researches in which gliadin preparations have been examined by the physico-chemical techniques now

available have shown the preparations to be non-homogeneous. Burk[18] made molecular-weight determinations on gliadin from osmotic pressure measurements in several solvents and found values ranging from 40,000 to 75,000. Using the ultra-centrifuge, Krejci and Svedberg[19] found a gliadin preparation to contain molecular species with weights varying upwards from 17,250. Similarly, Lamm and Polson,[20] using the diffusion technique, and Putman, Briggs and Gortner,[21] using the electrophoretic procedure of Tiselius, found gliadin to be non-homogeneous. The refractory nature of glutenin makes it less easy to study by such techniques, but there is indirect evidence, from studies on dispersions of gluten, that it may also be a mixture of several protein components.

It would also seem highly probable that the proteins extracted by water and aqueous salt solutions consist of a number of protein species. There is very little work reported on the fractionation of these extracts by modern techniques, but since a number of enzymes can be extracted from the wheat grain by water or salt solutions, it is clear that the soluble proteins cannot be classified adequately by the simple divisions of albumin and globulin.

The question of the presence in the wheat grain of conjugated proteins or of proteins bound in complex union with lipoids, phospholipoids and carbohydrate has received relatively little attention. Wheat germ contains nucleoproteins, but these have not been investigated in any great detail. A lipoprotein complex may be isolated from a petroleum-ether extract of flour. By treating this fraction with dilute acid in the cold, Balls and co-workers[22] have obtained in crystalline form a protein or high-molecular-weight peptide. It is noteworthy for its high content of cystine—about 16%. In flour this protein is probably linked with a phospholipoid.

The most noteworthy feature of the amino-acid composition of the proteins of the gluten complex is the high content of glutamic acid. The gliadin fraction is also characterised by a high proline content. Blish[23] has given the

following table for the amino-acid composition of gluten proteins, compiling the data from the best available sources. He has calculated the values to a total N content of 17·5%.

TABLE 3

	Gluten, %.	Gliadin, %.	Glutenin, %.
Arginine	4·3	3·2	4·7
Lysine	2·1	0·6	1·9
Histidine	2·4	2·1	1·8
Tyrosine	4·2	3·1	5·1
Tryptophane	1·1	0·9	1·8
Phenylalanine	2·0	2·5	2·0
Cystine	1·9	2·3	1·7
Methionine	3·3	2·3	—
Serine	—	0·1	0·7
Threonine	2·5	3·0	—
Leucine and *iso*Leucine	6·0	6·0	6·0
Valine	3·0	3·0	1·0
Glutamic acid	36·0	46·0	27·2
Aspartic acid	—	1·4	2·1
Glycine	—	1·0	1·0
Alanine	5·5	2·5	4·4
Proline	11·0	13·2	4·4
Ammonia	4·5	5·1	4·0

Table 3 shows that there are some striking differences between the amino-acid composition of gliadin and that of glutenin. Equally differences are observed in the amino-acid composition of the protein in different parts of the grain.*

The N content of wheat due to non-protein constituents is very small, although their importance may be considerable. An example [24] is glutathione present in the germ to the extent of about 0·4%—i.e., 0·01% of the whole wheat—which affects markedly the physical properties of dough and also the activity of certain enzymes.

Fat

The literature on the fatty material of the wheat grain is confused and often contradictory. This is partly because samples chosen for analysis have not been comparable and partly because of the differences in the techniques employed.

* See below, p. 117.

The amount of fat that can be extracted depends on the method employed. Herd and Amos [25] obtained the following figures using petrol ether alone and previous hydrolysis with alkali or acid and pre-treatment with 70% ethanol.

Material.	Petroleum ether, %.	Alkaline, %.	Acid, %.	Alcohol, %.
Patent flour*	1·16	1·64	1·70	1·99
Bran	4·18	4·34	6·73	4·99
Germ	7·82	8·80	9·62	10·31

Whole wheat contains 2·2–3·8% of total fatty material. The table above shows that, as with other components, the fat is unevenly distributed among the different anatomical parts of the grain. It should, however, be pointed out that the bran and germ fractions used in practically every investigation hitherto have been the mill products. These are not pure fractions—the so-called germ, for example, containing a considerable but varying proportion of bran and endosperm. This is shown very vividly by the figures of Hinton [1] for pure dissected embryo and scutellum.

		Properties of lipoid.		
	Petrol-ether extract, %.	Acid no.	Iodine no.	P content, %.
Scutellum	30·3	5·3	116	0·02
Embryo	15·4	3·7	133	0·03

We are now, however, aware of another factor. During milling a proportion of the fat from scutellum and embryo is squeezed out and picked up or absorbed by the powdered endosperm.[51]

The results confirm the differences in the chemistry of these two adjoining deposits of fat. This variation is also shown by the figures for fat content of different extraction flours milled from the same grist (Table 11).

Some idea of the nature of the differences can be obtained from the work of Sullivan and Bailey [26] on the lipoids of wheat germ and of Sullivan and Howe [27] on the lipoids of wheat flour, since comparable methods were used in both investigations. The results on the fatty acid composition are shown in Table 4.

* For an explanation of "patent" flour, see below, p. 73.

TABLE 4

	Total saturated acids, %.	Unsaturated acids, %.			Unsaponifiable matter, %.
		Linolenic.	Linoleic.	Oleic.	
Flour oil	15·6	3·8	46	34·6	5·5
Germ oil	16·0	3·5	52·3	28·1	4·0

In each case the saturated acid fraction was largely palmitic. The same was observed by Hilditch,[28] who found the following percentages of fatty acids in wheat germ oil:

Palmitic	13·8%
Stearic	1·0%
Oleic	30·0%
Linoleic	44·1%
Linolenic	10·8%

The fatty material from the wheat grain also contains a proportion of compound lipoids, the phospholipoids or phosphatides. Channon and Foster,[29] for example, separated phosphatidic acid, lecithin and kephalin from wheat germ, whilst Barton-Wright [30] found that the compound lipoid fraction in both germ oil and patent flour was largely the magnesium salt of phosphatidic acid with small amounts of lecithin and kephalin. In bran oil, on the other hand, the fraction consisted mainly of lecithin and kephalin. From the data given by Barton-Wright it would appear that flour oil contains relatively more compound lipoid material than does germ oil. Thus the petrol-ether extract of patent flour contains 20% of material insoluble in acetone, whilst that from germ contains about 6·5%. In this connection it is of interest to note that gluten contains a phosphatide-protein complex.[31] Presumably this type of compound is present in the endosperm and is only broken down to give petrol-ether-soluble lipoids by acid hydrolysis or treatment with alcohol.

From Table 4 it will be seen that the unsaponifiable fractions of flour and germ oil are 5·5 and 4·0% respectively. Barton-Wright obtained similar figures, but for bran oil

the figure was 12·1%. Important constituents in this fraction are the sterols, tocopherols and xanthophyll pigments. About 70% of the unsaponifiable fraction from oil consists of various sterols, whilst the flour-fat fraction contains only about 50% of mixed sterols. The sterols from both oils are considered to be similar, being largely the isomers of sitosterol together with dihydrositosterol. According to Sullivan and Howe,[27] most of the combined sterols occur as derivatives of palmitates.

Wheat, and wheat germ particularly, is one of the main sources of tocopherol available for human nutrition. The proportions of the different forms, α, β and γ, appear to vary with the variety and region in which the wheat is grown, the content of α-tocopherol or vitamin E being greater in wheats grown in the North American continent than in wheats grown in western Europe.

Originally the colouring matter in wheat was believed to be largely carotene or provitamin A. It is now, however, accepted that xanthophylls, particularly lutein, are the chief constituents. Zechmeister and Cholnoky [32] found that a sample of unbleached flour from Hungarian wheat had a xanthophyll content of 1–2·5 parts per million, whilst the carotene was not more than 0·01 p.p.m. In a similar study of American flour [33] the corresponding figures were 1·0–1·4 p.p.m. and 0·01–0·04 p.p.m. Bran is believed to contain carotenoids, flavones and decomposition products of the chlorophylls.

It is obvious that wheat oil is singularly complex, and it would well repay investigation by the newer techniques now available.

Enzymes

Certain enzymes present in the wheat grain itself are important in the germination of wheat, in the storage of flour and in bread-making.

In flour from normal wheat β-amylase alone is responsible for supplying the yeast added to the dough with food, beyond the small natural content of fermentable sugar, but it is able

to attack only the available starch (in the form of mechanically damaged granules or "ghosts"[14]); from this starch it produces about 60% of maltose, the residue being dextrins of *high* molecular weight. The picture is different with flour milled from partly sprouted grain, or with normal flour to which active malt has been added, because the α-amylase, in contrast to that in normal flour, is present in an active form. This enzyme is able to attack a larger proportion of the starch than is β-amylase, but it produces mainly dextrins of *low* molecular weight; these in turn are attacked by β-amylase, so that the two enzymes supplement one another in producing maltose. This sugar is then fermented by the yeast to produce alcohol and carbon dioxide, which causes the dough to rise.

Sprouted wheat is nevertheless dangerous, because too high an α-amylase activity causes excessive production of the dextrins of low molecular weight which in turn give rise to stickiness of the crumb and, even, total collapse of the loaf. This activity occurs particularly as the dough in the oven warms to above 65° C., when the starch—in course of gelatinisation—becomes very susceptible to enzymic attack, which does not cease until the temperature reaches about 80° C.

There are other enzymes in wheat which take part in the complete breakdown of starch. A considerable proportion of both α- and β-amylase is in the bound condition and not readily soluble in water. This fraction is released by the proteolytic enzymes including papain. The content of amylases in the wheat grain depends on the variety and cultural conditions. The enzymes are present mainly in the outer endosperm and in the scutellum, and appear to be absent from the embryo and aleurone layer.[34]

The *proteases* (protein-splitting enzymes) are present mainly in the germ and aleurone layer, and only to a very small extent in the endosperm. They tend to liberate amylase bound to protein and to provide additional amino-acids helpful to yeast activity.

Lipase and *lipoxidase* act on the fat in the grain or flour.

Lipase breaks it down into glycerol and fatty acids, and lipoxidase produces fat peroxides and ultimately aldehydes and ketones by oxidation. These latter give a tallowy smell and flavour to the flour and the bread made from it. This tallowiness is often encountered in flour that has been stored for very long periods. Lipoxidase is also probably the active agent in the natural bleaching and improvement in the baking quality of flour during storage. Lipase is concentrated in the aleurone layer [34] and germ, but the distribution of lipoxidase is not yet known.

Wheat contains a certain amount of phytic acid, present as mixed insoluble calcium–magnesium salts. This fact is of importance in connection with the availability of mineral salts.* During bread-making *phytase* catalyses the breakdown of these salts into two components, inositol and calcium-magnesium phosphates. Peers [35] has measured the distribution of the phytase in the wheat grain and obtained the following results. This is probably the first direct measurement of the distribution of a wheat enzyme.

Fraction.	% of total phytase.
Endosperm	34
Germ	3
Scutellum	15
Aleurone	40
Outer layers	7

The *oxidising enzymes* concerned in the respiratory mechanisms of the wheat grain are mainly confined to the germ. At first sight it would seem that their significance in relation to flour and bread is remote and negligible. This is almost certainly true for flours of very low extraction, but with flours of higher extraction containing some germ the presence of oxidising and reducing enzyme systems may be of some importance, because oxidation-reduction systems are involved in the complex problem of dough and bread quality. The systems involving the direct utilisation of molecular oxygen are of obvious interest in this connection. Of these, the cytochrome system has been shown to exist in wheat germ and its importance established by the isola-

* See below, p. 136.

tion of cytochrome C from wheat germ by Goddard.[36] Of the other terminal oxidases, the presence of polyphenol oxidase appears to be doubtful, but Waygood [37] has given evidence for the existence of a true ascorbic acid oxidase in wheat germ. The germ also contains peroxidase and catalase. A number of the dehydrogenases has been shown to be present, and, in relation to the postulated importance of sulphydryl compounds in flour technology, the demonstration of the presence of glutathione reductase in germ is of considerable interest.

Vitamins

Cereal grains, including wheat, are outstanding for their content of the various members of the B group of vitamins, all soluble in water, and of the fat-soluble vitamin E. There is an abundant literature dealing with the chemistry and properties of the different vitamins, but in many cases precise or satisfactory methods for their assay have not yet been developed. This applies to some of the B vitamins and vitamin E (α-tocopherol). Table 5 gives a list of the vitamins known to be present in wheat together with figures—in some cases very tentative—of the amounts present.

TABLE 5

The Vitamins in Wheat

Vitamin.	Average content in wheat, μgm./gm.	Sites in wheat grain of greatest content.	Function in man.
B_1	3·9	Scutellum, aleurone	Regulating carbohydrate metabolism.
Nicotinic acid	50	Aleurone	Regulating carbohydrate metabolism.
Riboflavin	2	Aleurone, endosperm	
Folic acid	0·5	" "	An anti-anæmia factor.
B_6	5	" "	None established.
Panthothenic acid	10	" "	" "
Biotin	0·1	Aleurone	Uncertain.
Choline	1000	Germ and outer layers	None established.
Inositol	2·5 mgm./gm.	Aleurone and scutellum	" "
p-Aminobenzoic acid	1 (*p*)	Unknown	" "
E	25 (*p*)	Probably germ but otherwise fairly uniform	Uncertain.
Linoleic acid, Linolenic acid, Arachidonic acid } F.	10 mgm./gm.	" " "	None established.
B_{12}	1–2 (*p*)	Unknown	Anti-pernicious anæmia factor.

(*p*) = possible value.

The complexity of the wheat grain is again apparent, not only from the length of the list, which incidentally emphasises the importance of bread as a food, but also because of the differences in distribution of these vitamins.

Minerals

Some of the more common mineral constituents have been included in Table 1, on p. 33. It is probably true to say that the mineral content of wheat is as diverse as that of soil. Many are present in such small amounts that inevitably the figures in the literature are often conflicting. An example is lead. Kent,[38] by the spectrographic method, found a figure of 1 part per million, whereas a well-tested chemical method from the same laboratory gave the figure of 0·1 p.p.m.[39] The following figures for some of the more common elements are quoted in the literature.

TABLE 6

Element.	Whole wheat (dry basis), mgm./100 gm.	Parts per million.
Arsenic	0·01	0·1
Iodine	0·007	0·07
Bromine	0·2	2
Cobalt	0·01	0·1
Copper	0·4–3·0	4–30
Manganese	2·4–5·0	24–50
Titanium	0·08	0·8
Nickel	3·5	35
Aluminium	0·4	4
Tin	0·09	0·9
Silver	0·04	0·4

Pringle has carried out much work on the minerals in wheat and flour.[40] He points out that the content of any one is determined by one or more factors, viz. variety, soil, moisture in the soil and growth period.

Table 7 gives the average analytical figures from twenty-five samples of the same variety of English wheat grown at the same time on the same soil. Varying amounts of chalk had been added to each of the five plots about ten years previously.

TABLE 7

The Mineral Constituents of Wheat; Effect of Applications of Chalk to the Soil

Plot.	$CaCO_3$ added, cwt./acre.	pH of soil.	Mgm./100 gm.				
			P.	Mg.	Ca.	Mn.	Fe.
A	Nil	4·4	342	109·8	35·3	7·78	3·05
B	37½	4·7	342	103·6	38·0	8·23	3·17
C	75	5·1	345	104·1	35·5	7·67	3·20
D	112½	5·9	357	108·0	33·4	6·46	3·13
E	150	6·1	356	111·6	33·5	5·52	3·11

One striking observation was that the yield of grain on the most acid soil was only 3 cwt./acre, compared with 15 cwt./acre on the least acid soil.

The phosphorus and iron contents were unaffected and the calcium and magnesium contents only slightly. Greaves and Hirst,[41] however, found that the calcium content of wheat grown in a calcareous soil was greatly dependent on the available moisture. Under dry farming conditions in Utah they found a minimum calcium content of 87·5 mgm./100 gm., rising to 223·6 with increasing amounts of irrigation water. Apart from yield, however, the most interesting fact brought out by Table 7 is the relationship between the pH of the soil and the manganese content of the grain.

The effects of variety and site on iron and manganese content are illustrated in Table 8, on p. 48.

Generally speaking, the bran and germ have the highest concentration of minerals, as shown in Table 9, on p. 49.

The iron content of flour is of some technical interest. Jones and Moran [42] have shown that in the milling of 80%-extraction flour an appreciable amount of iron finds its way into the flour and offals from the wear on the milling machinery; in their particular investigation on a commercial mill they observed an 11% increase, calculated on the initial iron content of the wheat, due to this accretion.

Table 8

Mineral Constituents of Wheat; Effect of Variety and Site

(Mgm./100 gm.)

Variety.	Site A.		Site B.		Site C.		Site D.		Site E.		Site F.		Average per variety.	
	Fe.	Mn.	Fe.	Mn.	Fe.	Mn.	Fe.	Mn.	Fe.	Mn.	Fe.	Mn.	Fe.	Mn.
Bersée	3·96	5·54	4·25	1·51	2·98	1·87	2·94	3·98	3·08	2·83	3·72	2·42	3·49	3·03
Holdfast	3·94	5·83	4·26	2·43	3·52	2·65	3·38	4·40	2·82	3·06	3·48	2·84	3·57	3·37
Jubilegem	3·64	4·90	4·02	1·76	2·78	2·42	2·76	3·60	2·80	2·97	3·36	2·47	3·23	3·02
Juliana	3·88	4·70	4·10	1·70	3·40	1·99	2·78	3·72	2·84	2·69	3·26	2·41	3·38	2·87
Little Joss	4·90	5·16	4·77	2·09	3·86	2·46	3·04	3·91	3·36	2·89	3·76	2·65	3·95	3·19
Redman	3·98	4·98	4·44	1·57	3·36	2·11	2·84	3·54	3·02	2·56	3·62	2·60	3·54	2·89
Rivet	4·07	4·42	4·14	1·69	2·78	2·00	2·78	3·46	2·88	2·53	3·16	2·12	3·31	2·70
Squarehead II	4·10	4·53	4·42	1·91	2·90	2·27	2·92	3·90	3·52	3·11	3·40	1·91	3·54	2·94
Squarehead's Master	4·18	4·54	4·20	1·84	3·00	2·18	2·76	3·70	2·77	2·72	3·16	2·43	3·35	2·90
Average per site	4·41	4·96	4·28	1·83	3·18	2·22	2·91	3·80	3·01	2·82	3·44	2·43	—	—

Note. Sites A–F represent different farms in Hertfordshire.

TABLE 9

The Mineral Constituents of Different Milling Products

(Mgm./100 gm.)

	K.	P.	Mg.	Ca.	Fe.	Mn.	Zn.	Cu.
White flour	151	127	30	20	1·4	0·8	1·9	0·2
Germ	930	1055	322	55	5·8	20·8	19·9	1·75
Bran	1265	1305	565	119	14·1	11·9	17·7	1·46
Wheat (whole)	453	380	157	51	5·1	4·0	4·4	0·7

THE CHEMISTRY OF FLOUR

The mechanics of flour-milling are outlined in the next chapter, but at this point it is desirable to state the meaning of percentage extraction as applied to flour. A flour of (say) 70% extraction means simply that 100 parts by weight of wheat have been milled to give 70 parts by weight of flour. There are practical aspects, as for example whether the 100 parts of wheat should be based on the wheat before or after cleaning, which need not be considered here.

Ideally, flour-milling is a process of accurate dissection; theoretically, a highly refined white flour should contain only the inner endosperm, a 70–75%-extraction flour the bulk of the endosperm, and an 80–90%-extraction flour or meal conforming to minimum nutritional standards, such as those laid down by the Post-War Loaf Conference,[43] should contain most of the scutellum and the aleurone layer—the former rich in B_1 and the latter in nicotinic acid and iron—the rest of the flour being endosperm.

In the milling of flour on a modern roller mill the wheat may be ground and separated into as many as twenty-four fractions or streams.[42] The composition of these different streams in terms of (say) vitamin B_1, nicotinic acid, fibre, protein and the different enzymes will vary widely, depending on the relative amounts of scutellum, pericarp and endosperm present. Table 10, for example, shows the amounts of the different streams and their content of certain nutrients in the milling of 80%-extraction flour on a medium-sized commercial mill.

Table 10

Composition of Individual Mill Streams Corresponding to National Flour (80·5% Extraction)

(Arranged in order of decreasing whiteness; all results expressed on a 13% moisture basis)

Flour Stream	Yield, %.	Composition							
		Protein (N × 5·7). %.	Fat, %.	Fibre, %.	Ash, %.	B_1, μgm./gm.	Riboflavin. μgm./gm.	Nicotinic acid. μgm./gm.	Iron, mgm./100 gm.
Group I.—The Creamy Group (Patent Flour).									
A	10·4	10·7	0·93	0·10	0·40	0·54	0·40	9·0	0·69
B	16·9	11·1	0·94	0·10	0·43	0·57	0·37	9·7	0·62
C	15·2	11·0	0·89	0·10	0·43	0·57	0·40	10·7	0·52
D	3·5	10·8	1·15	0·10	0·52	1·08	0·33	12·0	0·67
	46·0*								
B^2	2·6*	10·1	1·84	0·10	0·66	2·34	0·56	15·0	1·19
Group II.—The Greyish-cream Group.									
Sub-group (A):									
E	2·0	11·7	1·23	0·10	0·60	1·74	0·53	13·5	1·00
II Bk	3·5	14·0	1·25	0·18	0·63	1·02	0·60	18·0	1·10
CMD	3·5	12·4	1·29	0·15	0·65	1·68	0·68	19·4	1·18
FMD	2·9	12·4	1·28	0·20	0·66	1·53	0·61	13·5	1·18
	11·9*								
Sub-group (B):									
G	3·5	11·9	1·70	0·15	0·67	2·40	0·60	17·2	1·30
X	0·2	11·5	1·94	0·17	0·77	2·97	0·70	25·5	1·68
I Bk	3·2	11·6	0·88	0·19	0·57	0·54	0·52	18·0	1·00
	6·9*								
National flour (80·5% straight run)	—	12·0	1·43	0·202	0·724	2·67	0·69	19·2	1·41
Group III.—Just Slightly Poorer in Colour than National Flour.									
Tins	0·2*	11·7	1·46	0·37	0·74	1·65	0·64	24·6	1·84
Group IV.—The Brown Group.									
Sub-group (A):									
F	1·2	12·3	2·45	0·24	0·97	4·05	0·92	25·1	2·19
H	2·2	13·2	2·07	0·33	0·97	4·11	0·92	24·0	2·15
III Bk.	0·8	16·5	1·77	0·35	0·95	1·83	0·80	64·0	1·94
	4·2*								
Sub-group (B):									
Y	2·7	12·8	2·75	0·36	1·33	5·64	1·10	50·0	3·16
IV Bk.	0·9	16·0	2·54	0·41	1·82	2·85	1·44	84·0	4·04
	3·6*								
Group V.—The Dark-brown Group.									
J	1·4	17·7	5·35	0·97	3·24	32·40	4·00	32·9	8·50
K	1·2	15·6	3·65	0·90	2·17	16·20	2·60	56·5	5·53
L	1·3	17·3	4·37	1·01	3·15	19·80	3·20	101·0	7·97
M	0·6	17·9	4·93	1·29	3·34	22·50	3·25	133·0	8·45
M dunst redresser	0·6	19·2	5·85	2·38	3·65	25·80	3·55	111·0	9·65
	5·1*								
Coarse offals	7·1	12·4	3·86	10·85	5·78	4·95	2·89	296·0	11·80
Fine offals	12·4	14·3	4·69	8·30	4·57	10·38	3·40	188·0	12·20
Calculated weighted average of offals	19·5	13·6	4·39	9·23	5·00	8·40	3·21	227·0	12·1
Calculated weighted average of all products	100·0	12·31	2·01	1·97	1·56	3·81	1·18	59·8	3·49
Wheat (determined) values	100·0	12·37	2·03	1·97	1·51	3·87	1·28	57·2	3·14

* These eight groups total 80·5% of the weight of the wheat.

In passing, it should be pointed out that, from the nutritional point of view, the per cent. extraction of a flour is in itself only a guide; it is obvious, for example, from Table 10 that by compounding certain streams a flour of nutritional value greatly in excess of that in an 80%- or 85%-extraction flour could be produced, although its actual extraction would be much less than 80%.

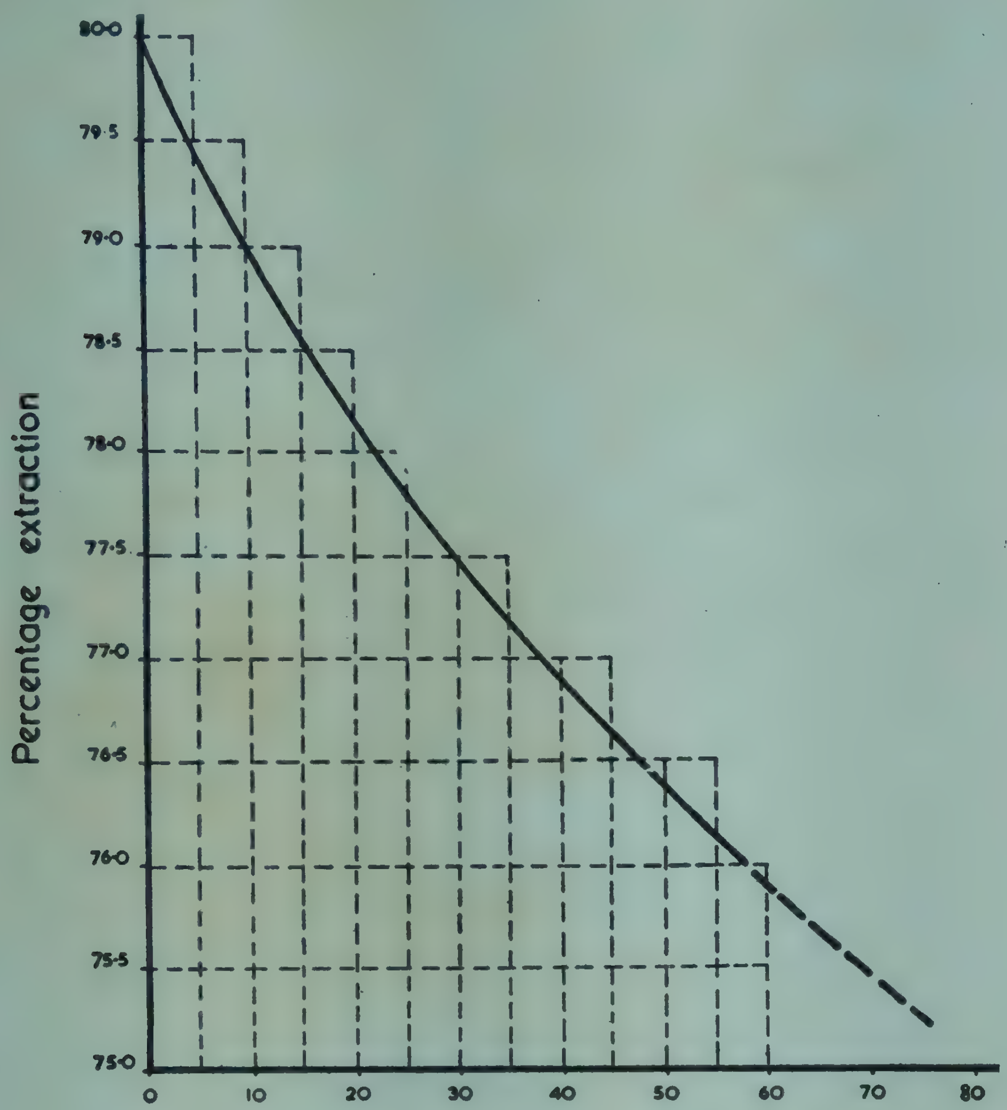

FIG. 11.—Graph showing the percentage white flour (of total flour) removed to leave residue equivalent to 80% National flour.

In 1953 the Ministry of Food, after extensive experiment in a number of laboratories, confirmed that in the milling of wheat it was possible to produce from the same grist both white flour *and* a flour equivalent in every way—nutrients, colour and baking quality—to the normal 80%-extraction flour. The relative amounts of the two flours must, however, be in strict ratio, this ratio depending on the *total* percentage of flour produced. Fig. 11 gives the ratio.

As an example of the use of Figure 11: if wheat is milled to an extraction rate of 77·5%, 30% of the flour so produced can be removed as "white flour", leaving the remainder identical with the conventional 80%-extraction flour, i.e., 100 parts of wheat milled in this way will give 23·25 parts of white flour, 54·25 parts of National flour, and the residue of the wheat, amounting to 22·5 parts, will be sold as wheat-feed for animals. These figures are in accord with those which can be calculated from the work of Jones and Moran.[42] This method of milling makes the most economical use of wheat when both white flour and 80%-extraction flour are required for the market.

The milling of 85%-extraction flour during the Second World War was a test of the British miller's skill in conforming to nutritional standards, whilst at the same time including the minimum amount of the outer fibrous layers of the grain which are largely indigestible and also have a deleterious effect on bread quality. The following figures give an idea of the success he finally achieved: [11]

	Theoretical composition, parts.	Average composition of commercial flour, parts.
Germ, particularly scutellum	2·5	1·9
Bran	None	3·4
Endosperm, including aleurone layer	82·5	79·7

When one considers (cf. Table 10) the complexity of the milling process and the fact that much of the wheat available was not of the best quality, this represents a considerable technical achievement.

As we have seen, the vitamins and minerals tend to be concentrated in the germ and aleurone layer. This latter is attached firmly to the seed-coat, so that the bulk is present in the bran. The germ likewise, because it is not so friable and readily powdered as endosperm, tends to congregate in the branny fractions. This is shown clearly in Table 10. It is Group V—the dark brown group—which is richest in B_1, nicotinic acid and iron as well as in fibre. Furthermore, Groups I–IV account for 75·4% of the wheat. It would be

Table II

Composition of Manitoba and English Flours

(Results calculated on a 15% moisture basis)

Percentage extraction.	Protein (N × 5·7), gm./100 gm.	Fat, gm./100 gm.	Carbohydrate (as starch), gm./100 gm.	Fibre, gm./100 gm.	B_1, i.u./gm.*	Riboflavin, μgm./gm.	Nicotinic acid, μgm./gm.	Ash, gm./100 gm.	Na, mgm./100 gm.	K, mgm./100 gm.	Ca, mgm./100 gm.	Mg, mgm./100 gm.	Fe, mgm./100 gm.	Cu, mgm./100 gm.	Zn, mgm./100 gm.	Total P, mgm./100 gm.	Phytate P, mgm./100 gm.	Cl, mgm./100 gm.
								Manitoba										
100	13·62	2·49	63·0	2·15	1·18	1·7	55·0	1·53	3·2	312	27·6	141·0	3·81	0·60	3·73	350	242·0	38·5
85	13·57	1·70	67·2	0·33	0·92	1·0	13·3	0·75	4·1	146	18·5	61·8	—	—	2·16	188	96·1	44·5
80	13·22	1·43	68·8	0·13	0·65	0·8	11·0	0·59	2·9	112	15·4	44·6	—	0·27	1·63	139	63·4	48·5
75	13·05	1·32	69·5	0·10	0·29	0·7	9·6	0·44	—	87	13·1	30·4	—	0·22	1·22	109	36·8	48·0
70	12·77	1·16	70·0	Trace	0·22	0·7	8·4	0·41	2·2	82	12·8	26·9	—	0·18	1·16	97	30·0	47·8
42	11·80	0·86	71·2	,,	0·09	0·5	7·0	0·34	1·8	71	11·1	21·5	—	0·15	1·00	82	14·0	45·0
								English										
100	8·89	2·23	66·8	2·08	0·96	1·7	48·0	1·52	3·4	361	35·5	106·0	3·05	0·65	3·16	340	233·0	35·5
85	8·55	1·46	72·0	0·42	0·84	1·2	10·5	0·70	2·9	179	24·5	35·0	2·22	0·36	1·77	153	72·8	42·2
80	8·21	1·28	73·5	0·19	0·60	0·8	9·0	0·58	2·1	151	21·5	24·0	1·65	0·27	1·30	118	57·1	44·4
75	7·98	1·13	74·2	0·15	0·42	0·6	8·0	0·46	2·2	118	19·2	16·8	1·35	0·22	1·02	93	30·4	44·9
70	7·92	1·04	74·5	Trace	0·28	0·6	7·5	0·43	2·1	111	18·9	13·9	1·40	0·22	0·97	84	25·1	45·0
46	7·64	0·76	75·8	,,	0·16	0·5	5·0	0·37	—	99	15·2	8·7	0·95	0·20	0·84	68	10·3	41·5

* The B_1 content of wheat or flour is expressed in different units by different workers. 1 i.u./gm. = 3 μgm./gm. = 0·3 mgm./100 gm.

expected, therefore, that in normal milling the curve relating extraction to content of certain nutrients would show a marked change in direction at about 75% extraction. Table 11 shows the results obtained in the milling of an all-Manitoba and of an all-English grist to various extractions on a laboratory mill.[10]

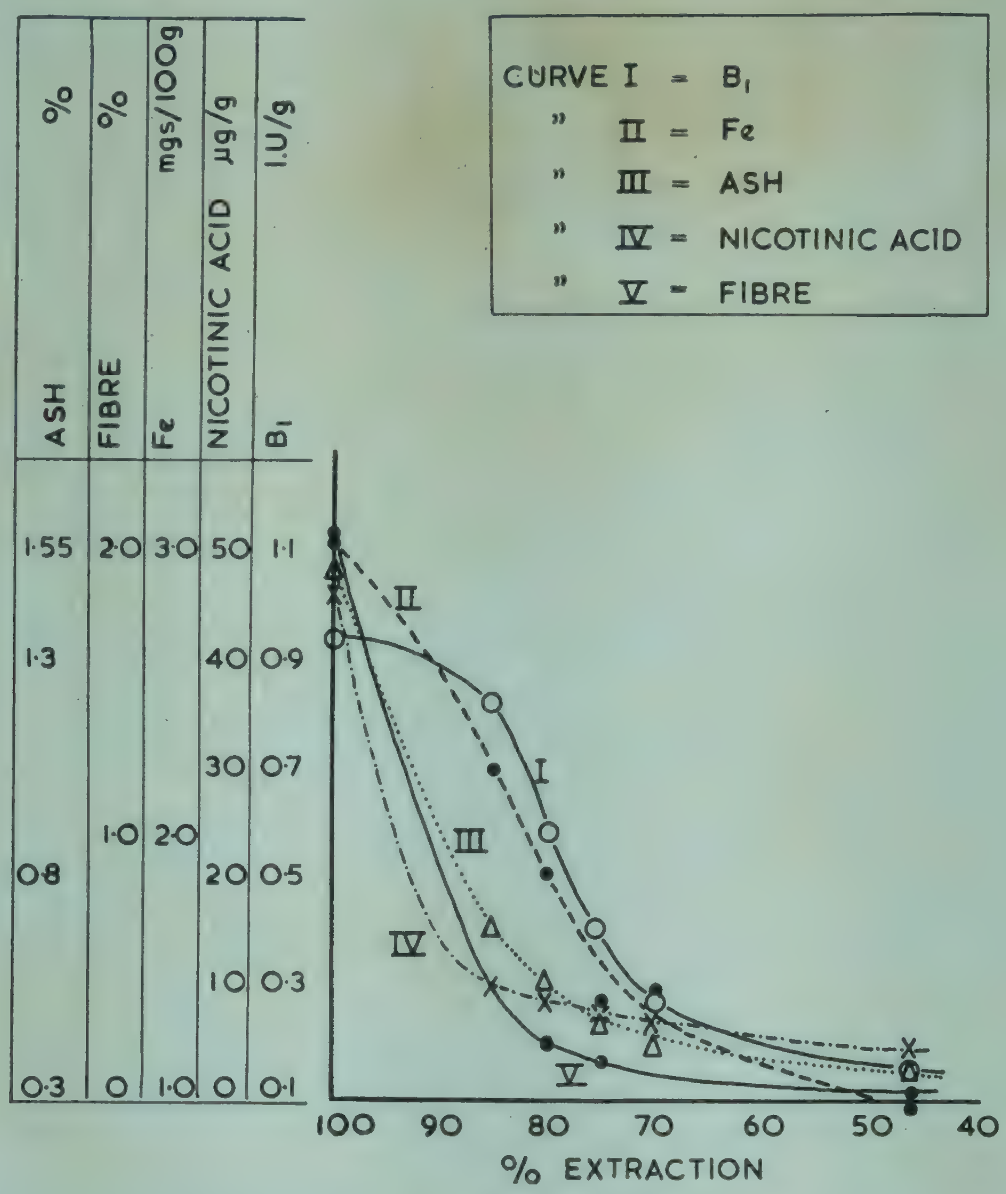

FIG. 12.—Graph showing the variation, according to extraction rate, in the content of certain nutrients.

Fig. 12 is based on Table 11. It indicates the significance of extraction in relation to the content of B_1 and nicotinic acid in flour milled from English wheat. The curve for B_1 changes direction markedly in the region of 75% extraction, but that for nicotinic acid in the region of 85%. The nicotinic acid, however, roughly follows the fibre and ash figures. This is to be expected, since the nicotinic acid is

TABLE 12

Composition of Certain Proprietary Flours used in Bread-making

(All at 15% moisture content)

Flour.	Character.	Protein, %.	Fat (acid hydrolysis), %.	Carbohydrate, %.	Fibre, %.	Ash, %.	Total calcium, mgm./100 gm.	*Creta* * present, oz./sk.	Fe, mgm./100 gm.	Mn, mgm./100 gm.	B_1, mgm./100 gm.	Nicotinic acid, mgm./100 gm.	Riboflavin, mgm./100 gm.
A	Whole wheatmeal	11·6	2·7	67·4	1·77	1·48	32·5	None	3·5	3·4	0·40	4·4	0·098
B	Wheatmeal	11·8	2·6	68·2	1·20	1·15	27·4	,,	2·8	2·5	0·30	2·8	0·097
C	,,	11·7	2·6	68·5	1·09	1·13	30·1	,,	2·7	2·5	0·29	2·8	0·097
D	Germ flour	12·6	3·2	63·6	0·94	4·65	118·2	8·5	3·7	3·7	0·48	2·9	0·11
E	,, ,,	14·1	3·4	63·8	0·62	3·08	32·5	none	3·1	3·6	0·30	2·3	0·11
F	,, ,,	13·5	3·5	63·7	0·69	3·56	36·2	,,	3·8	3·4	0·46	2·1	0·14
G	Malt flour	11·2	2·1	70·1	0·47	1·09	109·6	10·5	2·2	1·6	0·29	2·1	0·07
H	,, ,,	12·4	2·6	68·1	0·47	1·31	148·1	14·2	3·7	2·6	0·25	1·7	0·11
J	Gluten enriched	13·5	2·1	68·4	0·13	0·87	106·2	9·8	2·6	1·0	0·19	2·8	0·06
K	'National 80%-extraction flour	11·7	2·0	70·1	0·12	0·99	145·6	13·6	1·7	1·2	0·24	1·6	0·07

* The addition of *creta praeparata* at the rate of 14 oz./sack or mgm./100 gm. is now compulsory with all flours except true wholemeal (100%-extraction).

concentrated in the aleurone layer attached to the bran, and it is the bran content of the flour which largely determines its fibre and ash contents. The iron figures tend to increase rapidly above 80% extraction.

Table 11 shows the fall in phytate, and therefore of phytic acid, as the extraction is lowered. This also is to be expected, since the phytic acid is concentrated in the bran and to a lesser extent in the germ. The table gives no indication of the colour of the flours of different extraction nor of the breads made from them. Bread made from flour of 85% extraction and above is brownish in colour, bread from flour of 80% extraction off-white; below 80%, bread becomes increasingly white. The differences in colour below 80% extraction, although small, can be detected by the miller and are of considerable commercial importance.

Table 12 gives the composition of a number of proprietary flours, identified by their character in preference to their trade names. The analyses were carried out in May and June 1953, and obviously the protein content, for example, of such flours will depend on the wheats used, which will vary from time to time.

THE CHEMISTRY OF BREAD

The composition of ordinary bread is similar to that of the corresponding flour (cf. Table 11), after allowance has been made for the difference in water content. McCance and Widdowson [44] give figures for flours and the breads made from them which prove this (Table 13). The main differences—those in sodium and chloride—are due to the addition of salt during baking. There is also a destruction of up to 20% of vitamin B_1 during the baking process, depending on the oven conditions.[45]

In the case of certain proprietary flours (Table 12) the manufacturers recommend that fat and milk-powder should be added in the baking, whilst the amount of yeast used may be as high as 3·5%. In such cases, of course, the composition of the bread will be somewhat different from that

TABLE 13

Composition of Flours and Corresponding Breads *

	Moisture content, %.	Calories per 100 gm.	Protein, %.	Fat, %.	Available carbohydrate, %.†	Na, mgm./100 gm.	K, mgm./100 gm.	Ca, mgm./100 gm.	Mg, mgm./100 gm.	Fe, mgm./100 gm.	Cu, mgm./100 gm.	P, mgm./100 gm.	Cl, mgm. 100 gm.
Brown flour (90%-extraction)	15	343	11·6	1·9	74·2	3·5	205	24·0	73·0	2·80	0·44	223	41·0
Bread	39	246	8·3	1·4	53·3	(393)	147	17·2	52·3	2·01	0·32	160	(607)
National flour (80%-extraction)	15	350	11·2	1·4	77·6	2·6	127	17·8	36·4	2·15	0·27	132	46·9
Bread	37	259	8·3	1·0	57·5	(393)	94	13·2	26·9	1·59	0·20	98	(607)
White flour (70%-extraction)‡	15	350	10·8	1·1	78·9	2·1	93	15·2	21·7	1·90	0·20	92	46·7
Bread‡	36	264	8·1	0·8	59·3	(393)	70	11·4	16·4	1·43	0·15	69	(607)
Same bread, toasted	24	314	9·6	1·0	70·5	(467)	83	13·5	19·5	1·70	0·18	82	720

* None of the flours was enriched with *creta praeparata*. If they were (at the rate of 14 oz./sack), the calcium figures of the flours and the breads would be increased by 125 and 92 mgm./100 gm. respectively.
† Expressed as monosaccharides.
‡ Unenriched.

calculated on the flour alone; the protein content, for example, may be about 1% higher.

We can make bread only because of the cohesive and elastic properties of the gluten in the flour, and the character of its gluten determines to a large extent the quality of the flour for bread-making. A strong gluten gives a loaf of good volume and texture; on the other hand, a weak gluten which would give a poor loaf is essential for most biscuits.

Both the variety of the wheat and the environment in which it is grown affect the quality. Biffen in his classical work on the baking strength of wheats [46] demonstrated the importance of genetic factors and was able to breed from Red Fife another variety, Yeoman, which not only makes excellent bread but also satisfies agricultural requirements in yield and straw. For wheats of the Fife class there is a close correlation between loaf quality and protein content, which does not, however, apply generally to other wheats. The importance of environment is shown broadly by the relative merits of the world crops for bread-making.*

Strong wheats.	Medium or filler wheats.	Weak wheats.
Canadian Spring	U.S.A. Hard Winter	North-western Europe
U.S.A. Spring	Plate	U.S.A. Soft Winter
Russian Spring	Indian (Karachi)	Australian
	South-eastern Europe	

Greer [47] points out that in the North American prairies and the steppe-lands of Southern Russia spring sowing and the soil and climate tend to produce rapidly maturing grain of high protein content; most wheats which are capable of maturing under such conditions are suitable for bread-making. In contrast, wheats grown in north-western Europe are normally winter sown, mature more slowly in a climate of more even temperature and rainfall, and produce a higher yield of grain of low protein content. Under these conditions the majority of wheats yield flour of indifferent bread-making quality.

* See also above, p. 25.

Average commercial bread is based on the formula:

Flour	280 lb.
Salt	$4\frac{1}{2}$ lb.
Yeast	2–4 lb.
Water	15–16 gallons

ith a bulk fermentation of two to four hours and a proof of rty-five minutes. Fat may also be added at the rate of 2 lb. per 280 lb. of flour, and with white flour $\frac{1}{2}$ lb. of a w diastatic malt or $\frac{1}{4}$ lb. of a high diastatic malt may be lded to help gassing, crust colour and flavour. In some ses the dough is allowed to ferment overnight (up to twelve ours), in which case the amount of yeast is reduced, possibly $\frac{1}{2}$ lb., and the water to 14 gallons.*

Bread quality depends on a sufficiently strong flour coupled ith the correct addition of water and period of fermenta- on. The unique properties of gluten and dough have ade possible physical tests which indicate the optimum nount of water, the correct fermentation and/or the de- rable amount of chemical improver. These tests, based enerally on the viscosity and elastic modulus of the dough, ave given rise to a number of dough-testing instruments machines based or believed to be based on scientific rinciples. Halton, who did much of the pioneer scientific ork in this field, has recently reviewed the problem.[48]

A series of complicated chemical reactions occur in dough uring fermentation. Flour contains about 1% sucrose, nd this, together with the maltose produced by the amylases flour, is acted on by the yeast enzymes to produce glucose nd fructose, which are further changed by the yeast zymase alcohol and carbon dioxide.

The yeast activity depends not only on the sugar supply ut also on the available nitrogen, part of which is produced the flour proteases. Some of the proteases are also tivated by glutathione and certain other reducing sub- ances present in the flour. In addition to the diastatic nd proteolytic enzymes there are a number of oxidising stems which almost certainly modify the character of the

* See also below, p. 76.

flour gluten as fermentation proceeds. Even this is an over-simplification of the fermentation process. For optimum fermentation a wide range of substances must be present, including, in addition to the fermentable sugars, available nitrogen, phosphates, sulphates, magnesium, potassium, vitamin B_1, pyridoxin, etc. In excessive amounts, on the other hand, they may inhibit fermentation. Again, flour

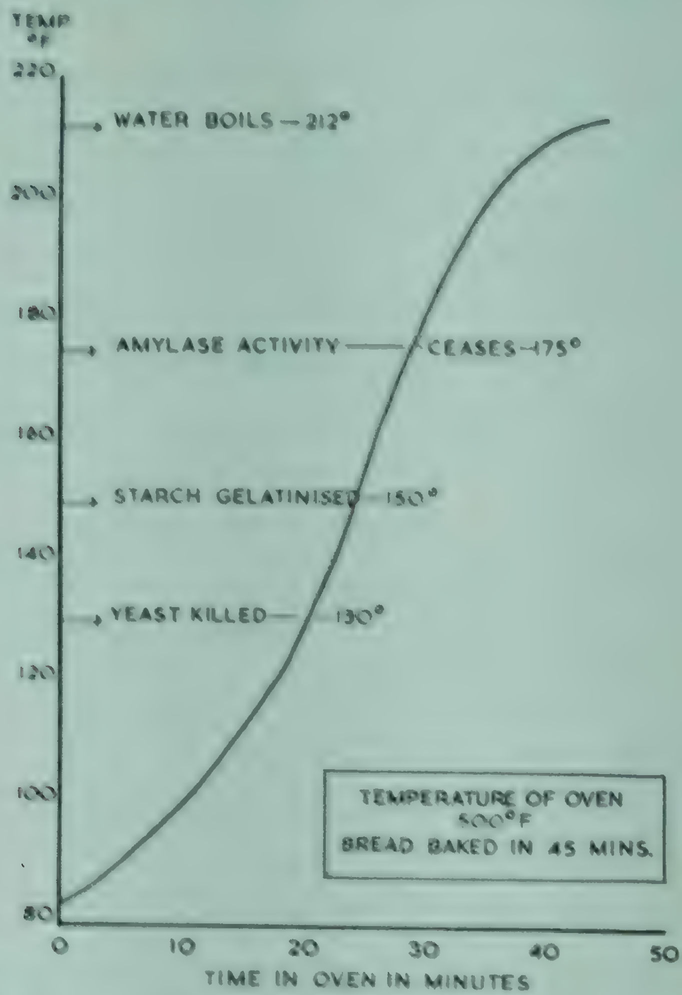

FIG. 13.—Graph showing the temperature at the centre of a 2-lb. tin loaf during baking.

contains substances which can kill the yeast-cells; one such is believed to be a lipoprotein. There is obviously scope for much research in the field of panary fermentation—" a dynamic process operating in a shifting and exceedingly complex environment ".

Fig. 13 shows the temperature at the inside of a 2-lb. loaf when it is baked at an oven temperature of 500° F. It is clear that diastatic action and yeast activity proceed for some time after the dough is placed in the oven.

The flavour of bread has recently been studied in careful and direct fashion. Many people claim that it should have no flavour because it is the one food eaten at all meals and with a wide range of other foodstuffs, many of them of pronounced flavour. Nevertheless, bread has a flavour, although in some cases it is very slight. Some will claim that fresh bread has a distinct taste apart from any question of its softness or texture. Baker, Parker and Footman in their study of flavour [49] point out that it arises from the ingredients, the fermentation and the baking. Bread made without any fermentation has no flavour. Again, if the fermentation is carried out separately by allowing the yeast to act on a sugar solution containing yeast nutrients and then using the fermented liquor to make a dough which is baked without any fermentation, there is a full bread flavour. Evidently the flavour attributable to fermentation arises from the action of the yeast on the sugar rather than on the other flour constituents. A large amount of yeast in itself gives a distinctive flavour. It is, however, in the baking that flavouring bodies are formed, particularly in the crust. When the oven vapours during the baking of bread are condensed, several substances of pronounced flavour, covering a range of alcohols, aldehydes and ketones, can be identified.

The moisture content of a whole loaf is approximately 38% and that of the crumb about 45%. With bread properly baked, the higher the extraction the higher the moisture content. As an approximate guide 1 part of flour of 70, 85 and 100% extraction will give 1·35, 1·37 and 1·40 parts of bread respectively.

Diluents

During the War, in order to save wheat, wheaten flour was diluted with potatoes, potato flour, barley, oats and rye. Careful consideration was given to the maximum amounts that could be incorporated without seriously affecting the quality of the bread. Two standards were set, the first signifying no appreciable effect, the second signifying a lowering

of the quality but still maintaining an acceptable loaf. It was also borne in mind that in the large plant bakery the dilution would need to be less, because of the difficulties in handling a sticky dough on mechanical mixers and conveyors. The amounts fixed by an expert panel appointed by the Ministry of Food were:

Diluent.	Type of bakery.	1st standard, %.	2nd standard, %.
Barley	Small	6–8	15
,,	Machine	5	10
Groats	Small	3	6
,,	Machine	2	5
Potato flour	Small	1–3	3–6
,,	Machine	1–3	3–6

Rye flour is the most satisfactory diluent; it can be used at much higher levels, namely, at about 12% and 25% respectively. Otherwise, the table is interesting in showing how little one can add of other cereals and flours and at the same time produce a reasonable loaf. The protein of rye approximates to wheat gluten more closely than does the protein of other cereals.

Staling

At normal temperatures bread becomes stale in two to three days. The changes that take place are still not understood, but in general terms the crumb becomes hard and friable, there is a loss of water by evaporation and the crust becomes tough and leathery, with an unattractive flavour. This hardening of the crumb is practically complete in about two days. Thereafter the hardness is accentuated by evaporation.

As already stated, the moisture content of the crumb of freshly baked bread is approximately 45%, that of the loaf as a whole 38%, and that of the outer part of the crust practically zero. As neither the crust nor the crumb is in equilibrium with the humidity of the atmosphere, the crumb tends to lose moisture, dropping ultimately to a moisture content of about 14%, and the crust gradually picks up moisture until it reaches the same level. The loaf as a

hole, however, steadily loses weight, forming first, just nderneath the crust, a narrow zone of hard, dry crumb hich gradually increases until in two to three weeks it ccupies the whole interior of the loaf. Before this loss of vater becomes appreciable the staling, i.e., mainly the nitial hardness of the crumb, can be reversed by re-heating ne loaf.

The consequences of staling are less apparent in a well-aked loaf of soft and good texture than in a poor loaf, lthough the rate of hardening is little different in either ase. This fact was emphasised during the last War, when very effort was made to maintain the quality of the loaf espite the difficulties over labour, the addition of non-heaten diluents to the flour, etc. It was held that this ot only helped to maintain morale but also reduced vastage of bread due to staling. In recent years, originally the U.S.A., but now also in this country, small amounts—pproximately 0·15%—of surface-active agents, e.g. glyceryl nonostearate, have been added to bread to keep it soft and o obscure the early stages of staling. Ordinary fat, such as rd, added to bread at the rate of about 2% of the flour veight, reduces slightly the hardening of the crumb and also cts as a bread improver. In this way it also reduces some-hat the rate of staling. Similarly, protein-enriched breads, y giving a stronger structure to the loaf, produce the effect f not staling so quickly. Both breads also have a softer rumb when properly made, and this in itself gives a greater hargin of time before the bread becomes unpleasantly hard.

Freshness in bread can be retained for much longer if it stored in suitable containers at freezing temperatures. High-temperature storage—i.e., at 40–50° C.—also tends to elay staling, but bread can be held at such temperatures r only about one day because of other changes producing ndesirable flavours.

The hardening of the crumb is due to changes in the elatinised starch and can be simulated in freshly cooked arch gels of 25–50% moisture content. These gels harden nd lose much of their capacity to absorb water in about

two days at ordinary temperatures. Furthermore, as they harden, their X-ray diffraction pattern also alters, and suggests an alteration in the gel structure from an amorphous to a crystalline state.

Recent work suggests that, in addition to the physical changes during staling, trace amounts of new compounds are present in stale bread, e.g., *iso*valeric and *iso*butyric acids, formed by the oxidation of the corresponding *iso*-aldehydes in the crust, which intensify the sensation of staleness in the palate. This theory is in accord with some observations by Bechtel, Meisner and Bradley.[50] They used a tasting panel of ninety-five to ninety-eight people, who assessed the degree of freshness of a normal loaf and a crustless loaf, specimens of which were tasted at different intervals after they had left the oven. The following is a summary of the results:

Age of bread, hr.	% freshness.	
	Normal loaf.	Crustless loaf.
2	—	—
20	87	87
44	75	74
68	52	72
92	44	68
116	38	68
140	14	63

The bread without crust clearly maintained its freshness longer, although other tests showed that there was no difference in the crumb compressibility, the ease with which it crumbled or the swelling power of both breads of the same age.

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CHAPTER FOUR

THE MAIN FEATURES OF THE MILLING AND BAKING PROCESSES

MILLING, and to a lesser extent baking, are complicated technical processes, and the good miller and the good baker are craftsmen. The smallest and the largest flour-mills are both mechanically operated and differ little in method or principle. The methods of the small " family " baker and of the large " plant " bakery, however, do not present a corresponding similarity, owing to differences, often marked, in their degree of mechanisation and in the functions of their craftsmen; nevertheless, the technical processes of both are the same is principle.

For a proper appreciation of the quality of bread it is desirable to know the essential steps in both the milling and the baking processes. The detailed technology of milling and baking is, of course, outside the scope of this book.

MILLING

A consignment of wheat, when it arrives at a flour-mill from overseas or from the farm, is unsuitable for milling immediately, because it is dirty and contains all manner of extraneous objects which might contaminate the flour and damage the milling machinery. Among the commoner foreign bodies found in parcels of wheat are pieces of sacking, string and rags, sticks and stones, bits of metal, lumps of mud, seeds of many kinds and dust.

The miller's first task, then, is to give the wheat a thorough cleaning and to remove all foreign bodies. He starts by removing the larger objects which might clog his conveying machinery. For this he employs machines which give the wheat a rough sifting; they also " aspirate " it, i.e., subject it to a current of air which carries off some of the lighter

particles of dirt and dust. The wheat is then placed temporarily in storage bins.

The detailed sifting and cleaning are left until the wheat is taken out of storage for milling. It then passes to a section of the mill known as the " screenroom ", containing a variety of machines, each specially designed to extract a particular kind of foreign body from the wheat. Accurate sifting machines remove impurities with larger or smaller dimensions than wheat grains; other machines incorporating indented surfaces remove those of the same diameter but different shape. Round seeds are removed from the grain by taking advantage of their faster rolling speed on an inclined surface; others are separated by their different behaviour in air currents. Magnets extract iron and steel fragments from the grain; other metals, and stones of the same size as wheat grains but with a different specific gravity, are separated when the wheat is washed. Washing, with the help of scouring and brushing machines, also dissolves away any caked mud and frees the individual grains of any attached dirt.

Cleaning is only the first stage of preparing the wheat for milling; a second and equally important stage is " conditioning ". Conditioning brings the wheat into the right physical condition for milling; it has been described as " the application of heat, water and air to wheat for certain lengths of time in such a way as to facilitate the best separation of bran from the endosperm and as far as possible to improve the baking value of the resulting flour ".

The importance of conditioning will become apparent in the outline of the milling operations described below. It is sufficient to remark here that for some of the operations a higher moisture content is desirable in the wheat than for others, and the miller therefore has to decide on a satisfactory compromise. In practice, owing to the variation in the initial moisture content of wheat arriving at the mill, the compromise reached often means that moisture must be extracted from some consignments but added to others. Drying is done by hot-water radiators and air currents.

Moistening or " tempering " is carried out either by " cold conditioning ", in which, to obtain uniform penetration, the wheat, damped in the washing process, is allowed to lie for one or more days, or by " warm conditioning ", in which the diffusion of moisture through the grain is speeded up by heat. To stabilise the gluten, and so improve the baking quality of the flour, the wheat may also be subjected to " hot conditioning " at a higher temperature. A final moistening just before milling is sometimes given to toughen the outer coat of the grains without increasing significantly their average moisture content.

The actual milling begins when the wheat, cleaned and conditioned, is delivered automatically to the first stage of the grinding machinery, known as the " first break ".

Here some recapitulation may be helpful. The grain is a seed formed of a thin outer fibrous coat, pale yellowish to dark reddish brown in colour, enclosing a compact mass of white endosperm together with the small yellow germ which is situated at one end of the grain. The aim in white-flour milling is to separate as completely as possible the outer skin and germ from the endosperm and to pulverise the latter. The modern milling process is designed to achieve this by exploiting certain natural peculiarities of wheat. These are:

(*a*) The toughness of the bran coat, which enables it for the most part to remain in relatively large pieces when subject to a tearing action which strips away and partially crumbles the endosperm.

(*b*) The following properties of the endosperm:

(i) A certain solidity or cohesion which allows the endosperm on being initially torn from the bran to remain mostly in the form of large fragments (known as " semolina ") which can readily be sifted and winnowed (" purified ").

(ii) A degree of friability which enables these fragments to be crushed to small size when submitted

to pressure (between rollers) without disruption of the accompanying pieces of bran.

(iii) A physical " liveliness "—by no means always present in powdered material—which facilitates sifting carried out in order to separate fine flour from particles (known as " dunst ") which have escaped being completely crushed, and in order to " scalp " (remove by means of relatively coarse sieves) any bran pieces which have been flattened by the rolling pressure.

(*c*) Softness and greasiness in the germ, causing it to be flattened much more than the bran by the pressure between the rollers. As a result it can subsequently be largely scalped away, in the form of relatively large discs, from both bran and endosperm.

All these peculiarities vary appreciably between different types of wheat and all are markedly affected by the conditioning process. In general, they are best utilised by means of a gradual breaking-down process. The normal modern milling process has about twenty separate grinds, each followed by appropriate sifting operations; in a sense these are consecutive, but it must not be thought that *all* the stock goes through *all* the processes; a portion of finished flour is in fact turned out from one or two grinds only.

The grain is torn open in the first break through the shearing action of grooved rollers rotating at a differential speed ratio of $2\frac{1}{2} : 1$. The effect is illustrated in Fig. 14.

The rollers, made of chilled iron, are grooved to a depth of $\frac{1}{40}$th of an inch, with about twelve " flutes " per inch arranged slightly spirally in relation to the axis of the roller, in order to aid the shearing action. The ground material, or " chop ", from the first break contains endosperm (known as the " release "), in various stages of subdivision, which is separated by means of a sifting machine from the larger pieces of opened-out grains, which are really bran-flakes with a thick coating of endosperm on one side. These go forward to a second break, whose rollers, more finely

fluted and set more closely together than the first-break rolls, scrape away further particles of endosperm. Third, fourth and fifth breaks repeat the process; after the last, relatively little endosperm is left adhering to the bran, which then leaves the system as one of the by-products known as "wheat-feed".

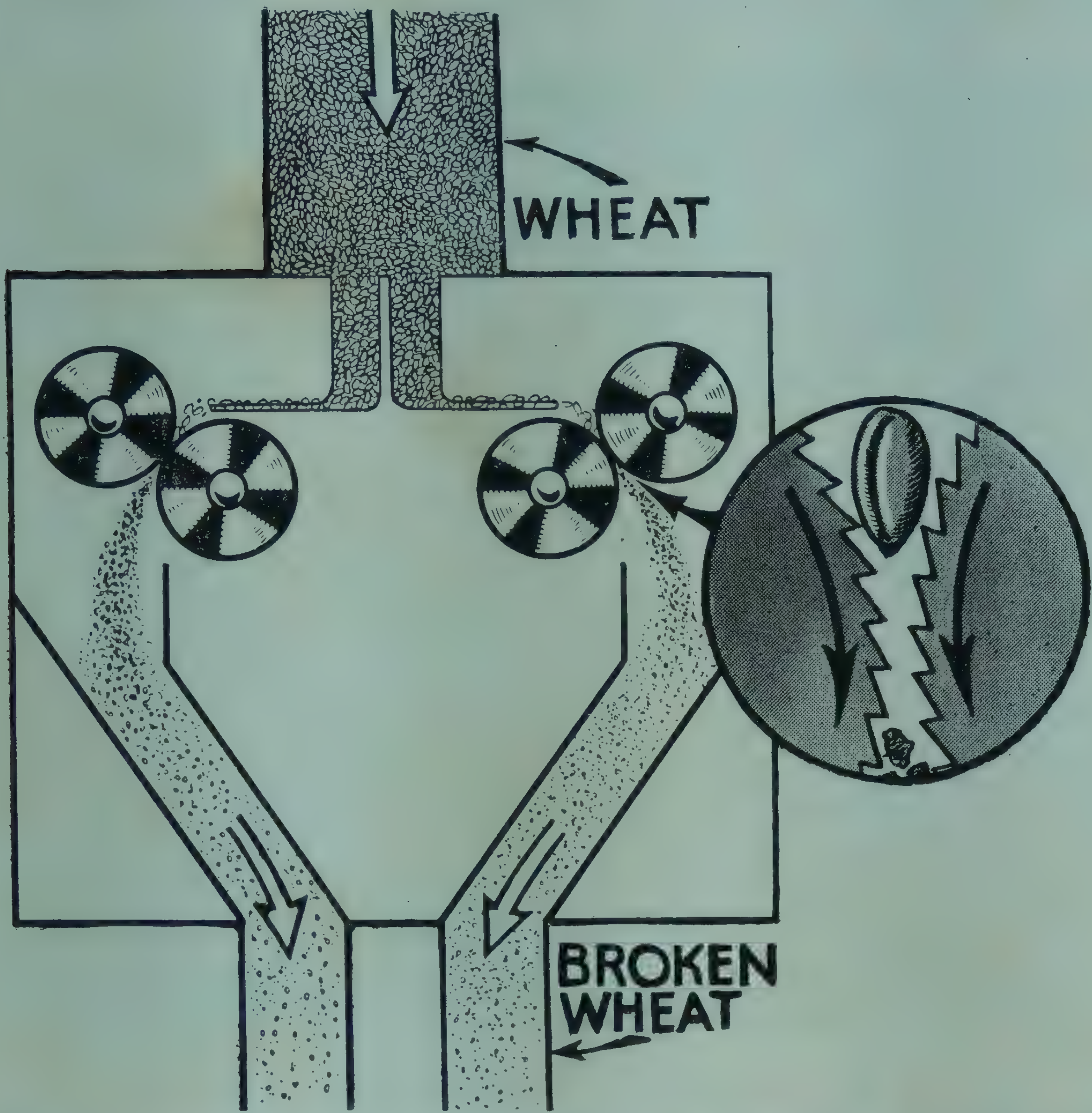

FIG. 14.—Diagram illustrating the shearing action of the break rolls.

In an efficient white-flour mill the release, at any rate from the early breaks, contains the endosperm mostly as coarse particles (semolina); these are best adapted to subsequent separation of bran fragments which unavoidably enter the release to some extent during breaking. The rollers also break down some of the endosperm into particles of intermediate size (known, progressively, as "middlings" and "dunst") together with a small proportion of "break

flour ". The release, in practice, is very thoroughly graded, or classified by particle size, in sifting machines. The break flour, as part of the final product, is removed from the system, whilst the dunst goes direct to a second series of rollers known as the " reduction system ". The semolina and middlings proceed, according to category, to their respective " purifiers "—machines which, by sifting and aspirating, extract

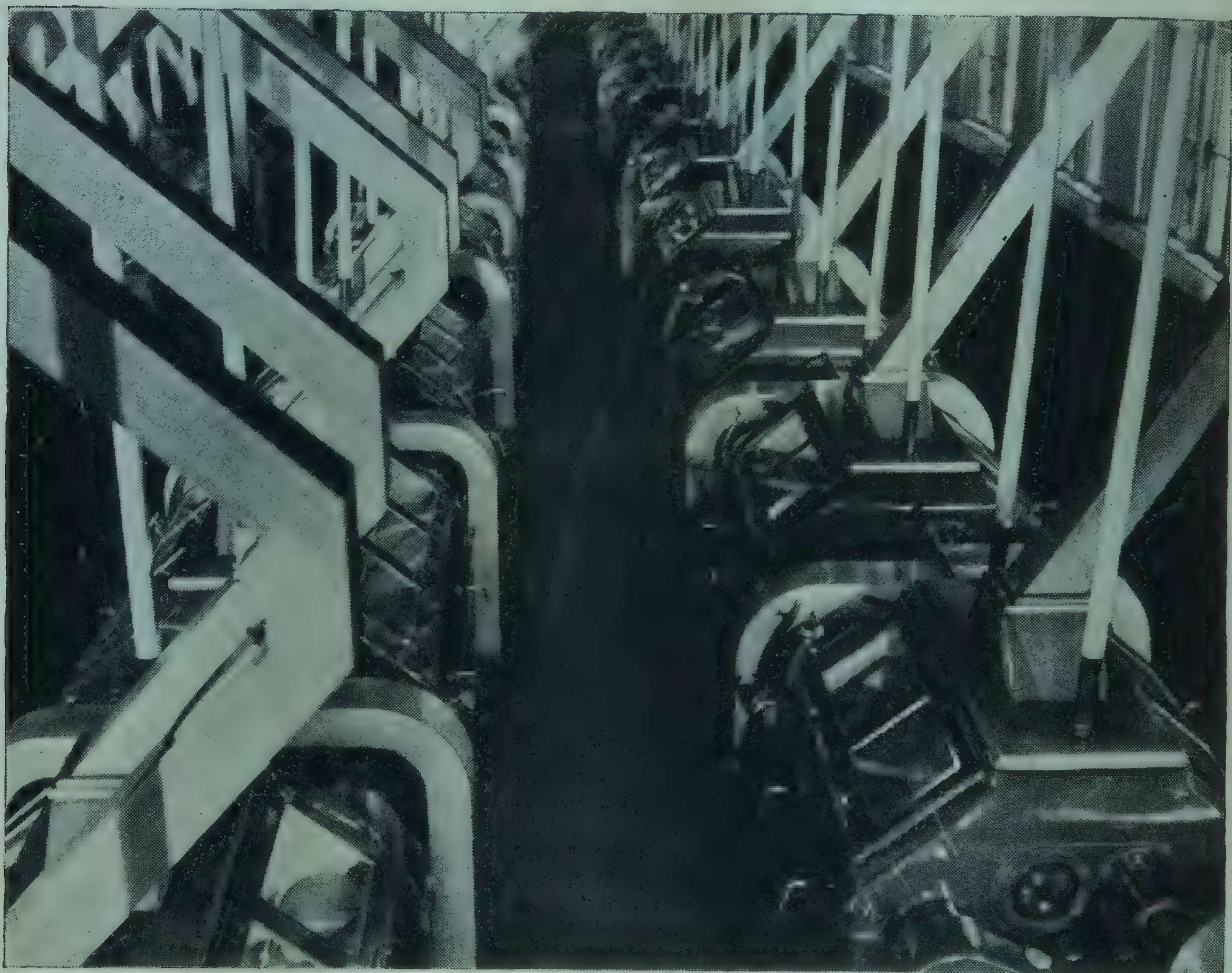

FIG. 15.—A roller floor in a modern mill.

most of the particles of bran. The bran is then removed as wheat-feed, and the residue of relatively pure endosperm is sent on to the reduction rollers. A third product, particles of endosperm with bran adhering, is despatched to a subsidiary system of rollers, graders and purifiers, called the " scratch system ", whence its products rejoin the main system at appropriate points.

The reduction rollers which receive the endosperm are similar to the break rollers but of smooth surface and rotating

at a differential ratio of $1\frac{1}{4} : 1$. Some of them take the finer stocks from the purifiers, some the coarser. Their function is to reduce the endosperm to flour and to flatten, without shattering, the remaining bran, thus making the final separation easier. This last is made by a further series of sifting machines, which sift out the flour from the stock after each reduction, the residue proceeding either to subsequent reduction rollers or being diverted to wheat-feed. In the reduction system the importance of correct conditioning of the wheat beforehand again becomes apparent: the endosperm, to crumble easily on the rollers, must have a certain moisture content; yet, if the stock is too damp, the sifting will be impeded and the endosperm may " flake " (flatten) rather than crumble during the rolling.

A simplified diagrammatic representation of the entire milling process is shown as Fig. 16.

The wheat-feed removed from the stock at various stages is processed to make animal feeding-stuffs. It is divided by the miller, according to the size of the particles, into two main categories, bran and fine wheat-feed, and either sold as such or further graded—the former into broad, medium and fine bran, and the fine wheat-feed into weatings, sharps and similar products.

It will be evident that flour is produced at many different points in the milling system. In an average mill, up to two dozen flour-streams are blended together to form a " straight-run " flour; the extraction rate is therefore the ratio, expressed as a percentage, of the weight of the straight-run flour produced to that of the wheat milled.

The flour streams differ greatly in colour and degree of " contamination " with bran. The whitest and least specky are derived from the reduction of the best purified semolinas and middlings and, if blended together, form what is generally known as a " patent " flour, whose percentage of the whole wheat amounts to 20–40%.

In normal times the plant is adjusted to suit an extraction rate of about 70%. Roller mills are, however, with relatively little modification, able to mill to any

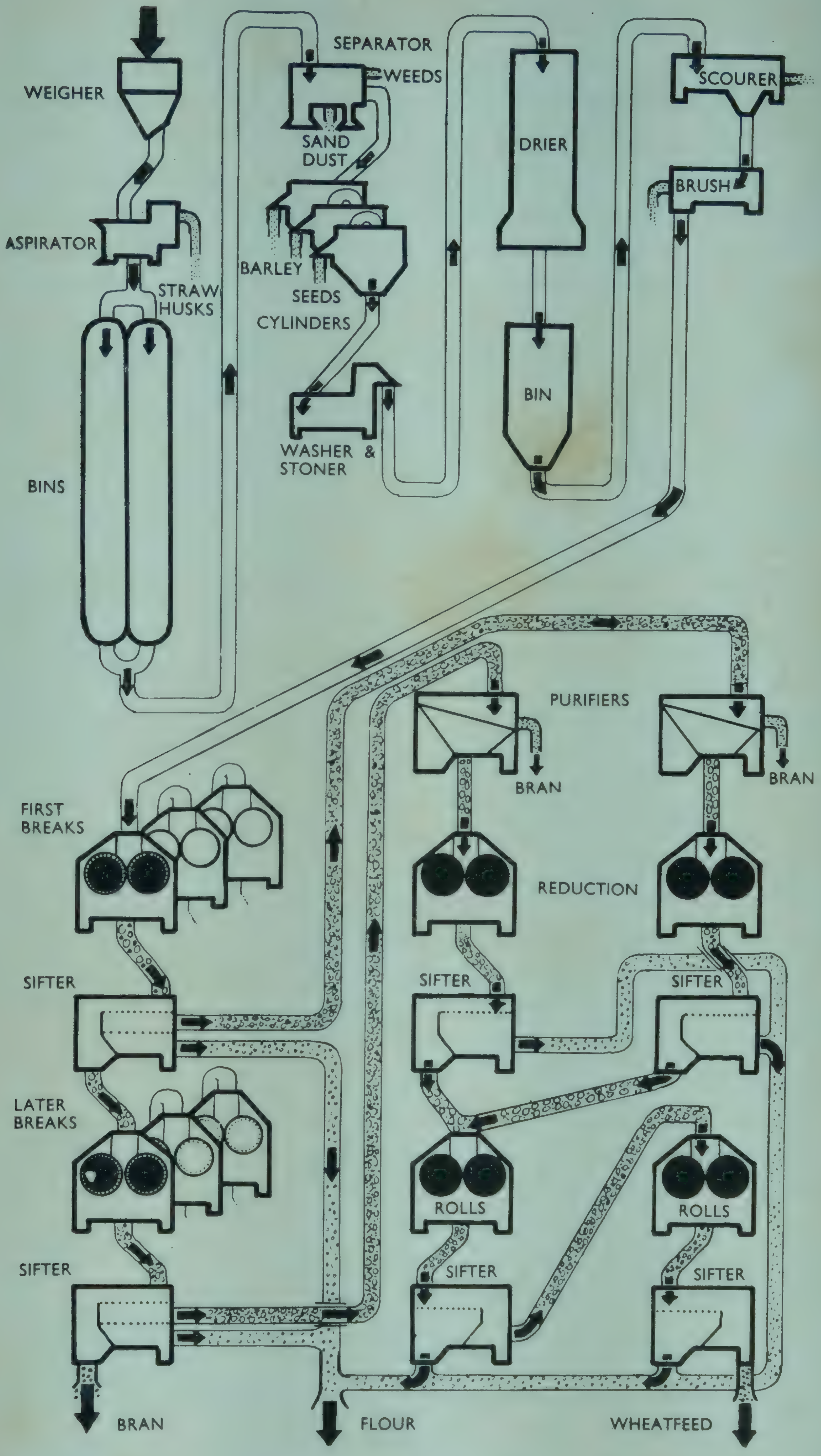

FIG. 16.—A simplified flow sheet of a mill.

extraction, and in fact during and after both World Wars the extraction rates prevailing in the United Kingdom and other countries were changed on several occasions.* British millers in 1942 were faced with the additional problem of ensuring that the 85%-extraction flour produced conformed to certain nutritional standards. They solved the technical difficulties involved mainly by changing the "balance of the mill", so that a much larger release was made earlier in the system.[1, 2] The endosperm in this release was necessarily of smaller particle size and more contaminated with bran than is desirable in white-flour milling, but the change had the advantage of leaving the later machines free to do more searching work in releasing additional proportions of endosperm from more branny stocks. The new knowledge that vitamin B_1 resided mainly in the scutellum was utilised by installing finely fluted rollers at points in the flow where by research the scutellum had been shown to concentrate; these rollers pulverised the scutellum without shattering the bran unduly. These steps were aided by a reduction in moisture content of the mill feed, which, though inevitably making the bran more prone to powder, increased the ease with which endosperm could be scraped off bran-flakes and also increased the friability of the scutellum.

The characteristic feature of modern flour-milling is that it is a gradual process. Despite the conventional use of such terms as "tearing", "crushing" and "pulverising", it is also a relatively gentle process. We have already seen † how the endosperm in the wheat grain is made up of distinct cells varying in size and shape according to their position in the grain, and which in the case of hard wheats tend, under slight pressure, to fracture at the boundaries of the cell walls. It is therefore of considerable interest to find that in the finished flour from a commercial mill clumps of these cells can still be observed under the microscope.[3]

* See below, p. 169. † See above, p. 31.

BAKING

The baker is chiefly concerned with two qualities in the flour that he receives from the miller, its strength and its colour. By " strength " he means its ability to produce a dough of the right degree of elasticity and stability which will give a loaf that is large and well piled.* To obtain the necessary strength, he may blend weak flours with strong ones. The colour of the flour is important in that it affects the colour of the bread, and the baker's customers in general prefer a loaf whose crumb is white.

Flour is the largest ingredient of bread, but it is not the only one. The baker's first task is to mix the flour with three other essential ingredients—water, yeast and salt—to form a dough. The proportion of water added is a little more than half the weight of the flour, on average, strong flours having a higher capacity for absorbing water than weak flours, so giving a greater yield of bread. The mixture of flour and water gives a dough which has elastic and plastic properties; yeast is added to make it ferment with the production of carbon dioxide, which gives the bread its light porous structure, and salt is added to flavour it.

The dough is mixed until homogeneous and then left to ferment under the action of the yeast. The period of fermentation can be varied to suit the baker's convenience. A " long " dough of eight to twelve hours is prepared in the evening by a baker who wishes to have a night's rest before baking his bread in time for the morning delivery; a " short " dough of two to four hours suits a bakery with a large and continuous output where night shifts are worked.

Long and short doughs are made to produce similar loaves by regulation of the amount of yeast added to the mixture. A long dough requires less than 1 lb. of yeast for every 280-lb. sack of flour; a short dough requires 2 to 4 lb., a very short dough as much as 5 lb., to give the same results. The quantity of salt used may also be varied, a long dough being

* See also above, p. 25.

given $4\frac{1}{2}$–6 lb. of salt, a short one $3\frac{1}{2}$–4 lb. The temperature at which the dough is kept is adjusted according to the duration of fermentation, 75° F. being suitable for a long dough, 80° for a short one.

During fermentation the enzymes present in the yeast act on the sugars of the flour as well as those produced from the starch by amylase activity. Invertase converts the sucrose into invert sugar, maltase converts the maltose into glucose (dextrose), and a third enzyme, zymase, converts the invert sugar and glucose into carbon dioxide and alcohol. The physical effect of this last action is seen in the rising of the dough. The baker may interrupt fermentation to " knock back ", or knead again, the dough, with the object of invigorating the process and expelling gas; but otherwise it is allowed to continue until the dough is " ripe ", i.e., until it has developed the necessary degree of elasticity and extensibility—which condition the baker judges by feel.

When ripe, the dough is " scaled off ", or divided into pieces of uniform size calculated to yield loaves of full weight after allowance has been made for evaporation during baking. Following an interval of ten or fifteen minutes to permit the dough to " recover ", the pieces are moulded into the shape of the loaves. A longer interval, of forty to sixty minutes, the " final proof ", allows the fermentation to become active again and the dough to rise once more.

The dough is now ready for the last stage—baking. The pieces are baked for about three-quarters of an hour in an oven heated to a temperature of 450–500° F. The water vapour and gas expand, the starch gelatinises, the gluten cells coagulate, the crust forms by dextrinisation, and so the loaf assumes its familiar appearance.

More popular with some bakers than the " straight-dough " system outlined above is the " sponge-and-dough " system. A sponge, consisting of part of the flour, a corresponding proportion of the water and all the yeast, is allowed to ferment for a time, before the salt and the remainder of

the flour and water are added; the mixture then ferments as a whole. This procedure, although it necessitates more work than a straight dough, has the advantages of requiring less yeast, of greater flexibility in the control of fermentation time and of yielding rather larger loaves with softer crumbs. Bakers in certain countries and localities also favour the inclusion in the dough of additional ingredients—malt to increase the maltose content of the flour, chemicals to stimulate the yeast and condition the gluten, and fats, oils or milk to improve the texture and food value of the loaf.

During summer weather certain substances, usually of an acid nature, such as acetic acid or acid calcium phosphate, may also be added to the flour or dough to prevent the development in the bread of a condition known as "rope". This becomes apparent first as a slight fruity (pineapple) odour, then the odour increases in intensity and the crumb becomes sticky; later still the crumb turns brown and reaches a condition in which it can be drawn out into fine filaments. Rope results from the presence in the flour of spores of *B. mesentericus* or *B. subtilis*.[4] These spores are not killed during baking and will develop in the loaf if it is kept at a sufficiently high temperature, i.e., 80° F. or over. They will not develop if the bread is cooled thoroughly after baking and kept cool. When weather conditions make this difficult, the miller may add 1–2 lb. of acid calcium phosphate to each sack of flour, or the baker may add 1–2 pints of 12% acetic acid to the dough produced by each sack of flour. These additions inhibit the development of the rope spores.

The processes involved in preparing the dough, whatever its composition, and its movement from one stage to the next, are performed partly or wholly by hand in small bakeries, as they are in home baking; large bakeries, on the other hand, are almost entirely mechanised. Included in the equipment of a modern plant bakery are: (i) tempering tanks to supply the right amount of water at the right temperature for (ii) mechanical mixers whose arms knead (and knock back) the dough; (iii) dividers and moulders to scale off

and shape the dough; (iv) automatic proving cabinets which control the duration and temperature of proving; (v) automatic travelling ovens through which the loaves progress on moving belts; and (vi) machines to slice and wrap the finished article. Everywhere in the bakery moving belts convey the dough or loaves from one stage to the next.

FIG. 17*a*.—A high speed mixer, with dough falling into a proving pan.*

Whatever mechanical aids may be available to the baker, his work calls for special skill and experience. These attributes find ample scope in the adjustment of the factors under his control, e.g., the quality and proportions of the different ingredients and the timing of the different stages of the baking process. Bread can suffer from many faults in appearance, texture and flavour if the baking is in any way haphazard.

* For Figs. 17*a–e* we are indebted to Mr. R. D. Mason, Director of Research, Allied Bakeries, Ltd.

FIG. 17*b*.—Dough fermenting. Thermometer in the nearest pan.

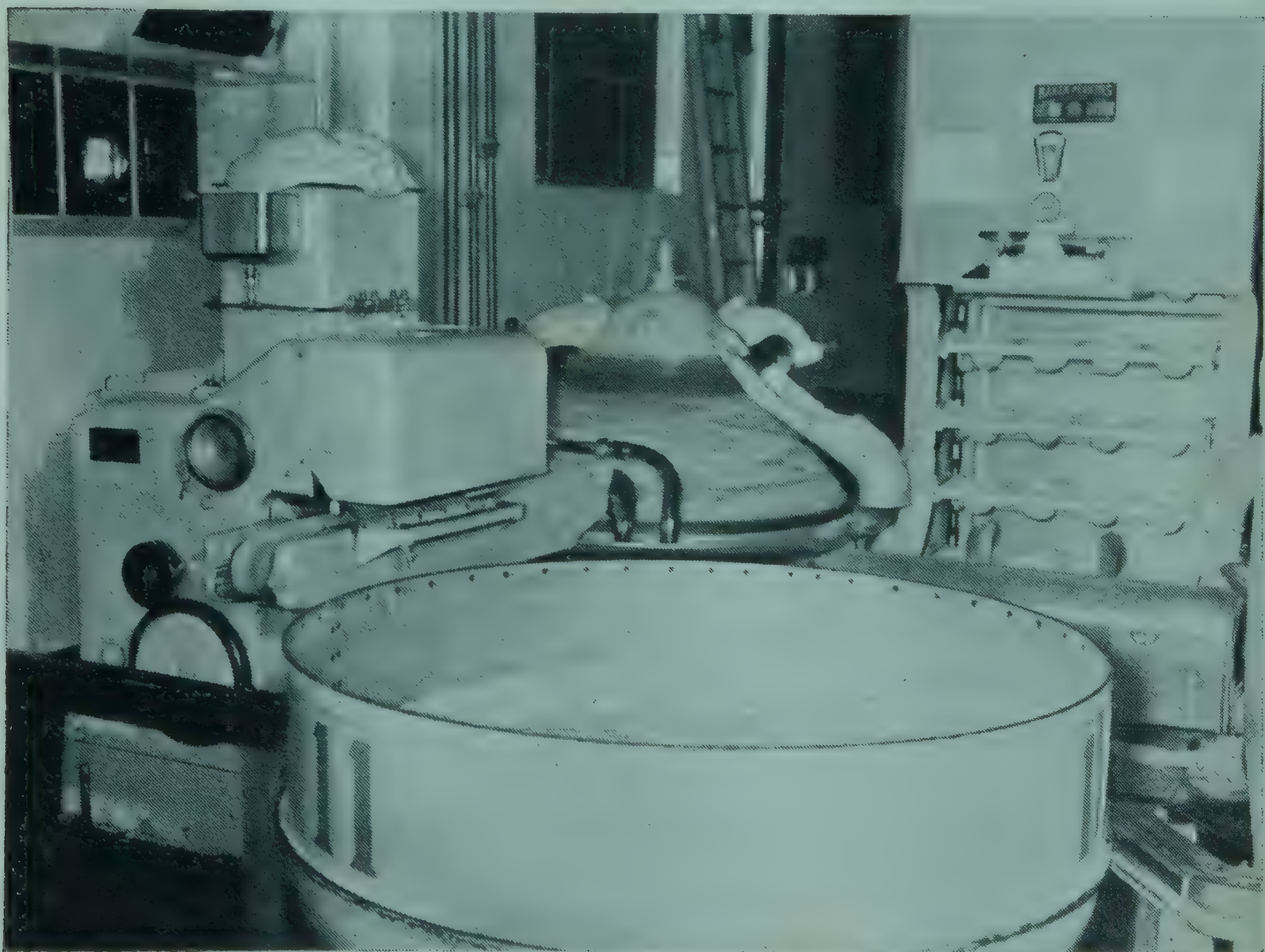

FIG. 17*c*.—Dividing the dough; passing it to the first moulder and thence to the first prover.

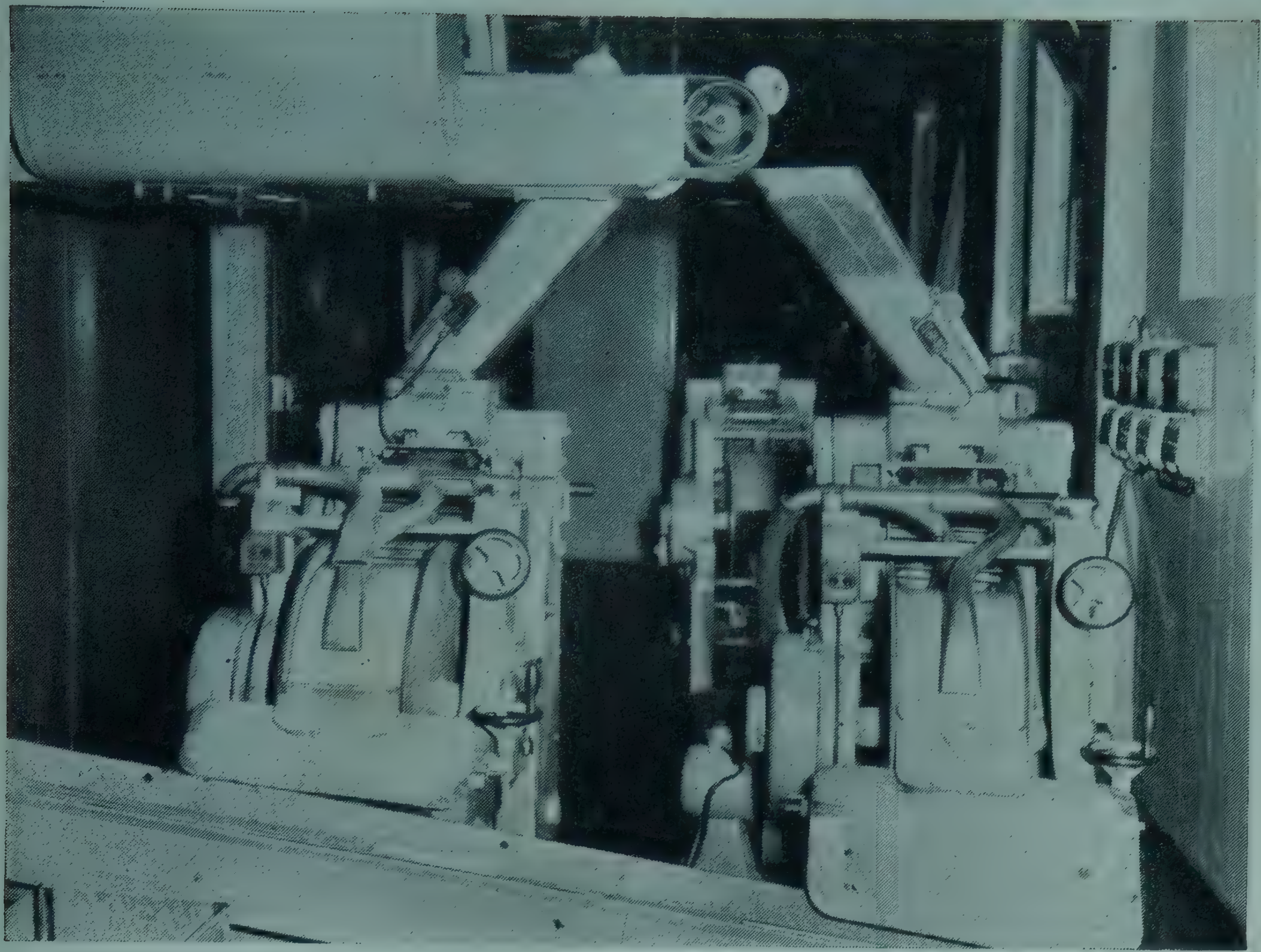

FIG. 17*d*.—Dough from the first prover receiving its final moulding, with travelling band in the foreground taking dough to tins for final proving.

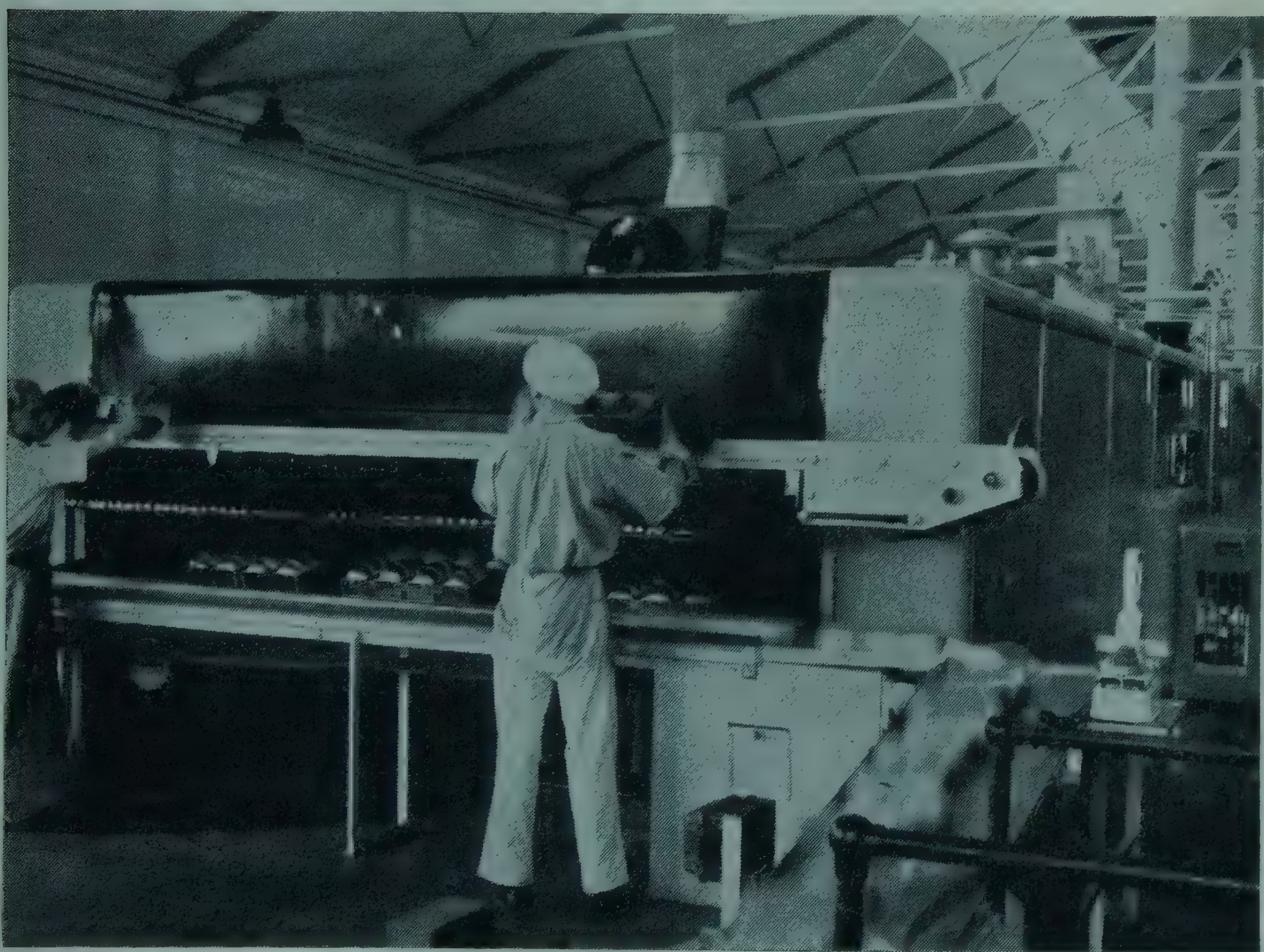

FIG. 17*e*.—Loaves emerging from the travelling oven.

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CHAPTER FIVE

IMPROVING AGENTS

To most people a good loaf must be "well risen", and the bread, when cut, should have a fairly close-grained uniform texture and be smooth, soft and elastic to the touch; the skilled baker will also look for points in the outside appearance and crust which will indicate to him whether the flour was of good bread-making quality and whether it was properly baked. In addition, most of the people in this country prefer the whitest bread available, and it is for this reason that many of the large plant bakeries mould the dough in a special way before it goes into the tin, in order to enhance its apparent whiteness.

Judged by these standards, freshly milled flour does not give the best bread, but if it is stored at ordinary temperatures its bread-making quality improves from the point of view of both the texture of the loaf and its colour; the scope for improvement is greater in the higher-extraction flours than in low-extraction or patent flours. Thus, to quote one experiment carried out in 1947 on 85%-extraction flour[1]: the flour was stored from June to December, and at intervals 2-lb. tin loaves were baked by a standard procedure. The following figures give the heights of the loaves:

Period of storage of flour, months.	Height of loaf, in.
0	5·8
3	6·1
4	6·2
5	6·6
6	6·5

The flour required about six months' storage to reach its optimum baking quality. On the other hand, a patent flour under the same conditions showed no significant improvement, the height of the loaf being constant at 7·3–7·4 in. over the six months' period.

The storage of flour for a period of months raises serious

economic problems. It is for this reason that chemical improving and bleaching agents have met with such ready success. A small amount of one of these substances added to flour when it is milled will at once give the same improvement in bread-making quality as that achieved after months of storage. If the substance is, in addition, a bleaching agent, the colour of the bread may also be whiter than that made from old or long-stored flour.

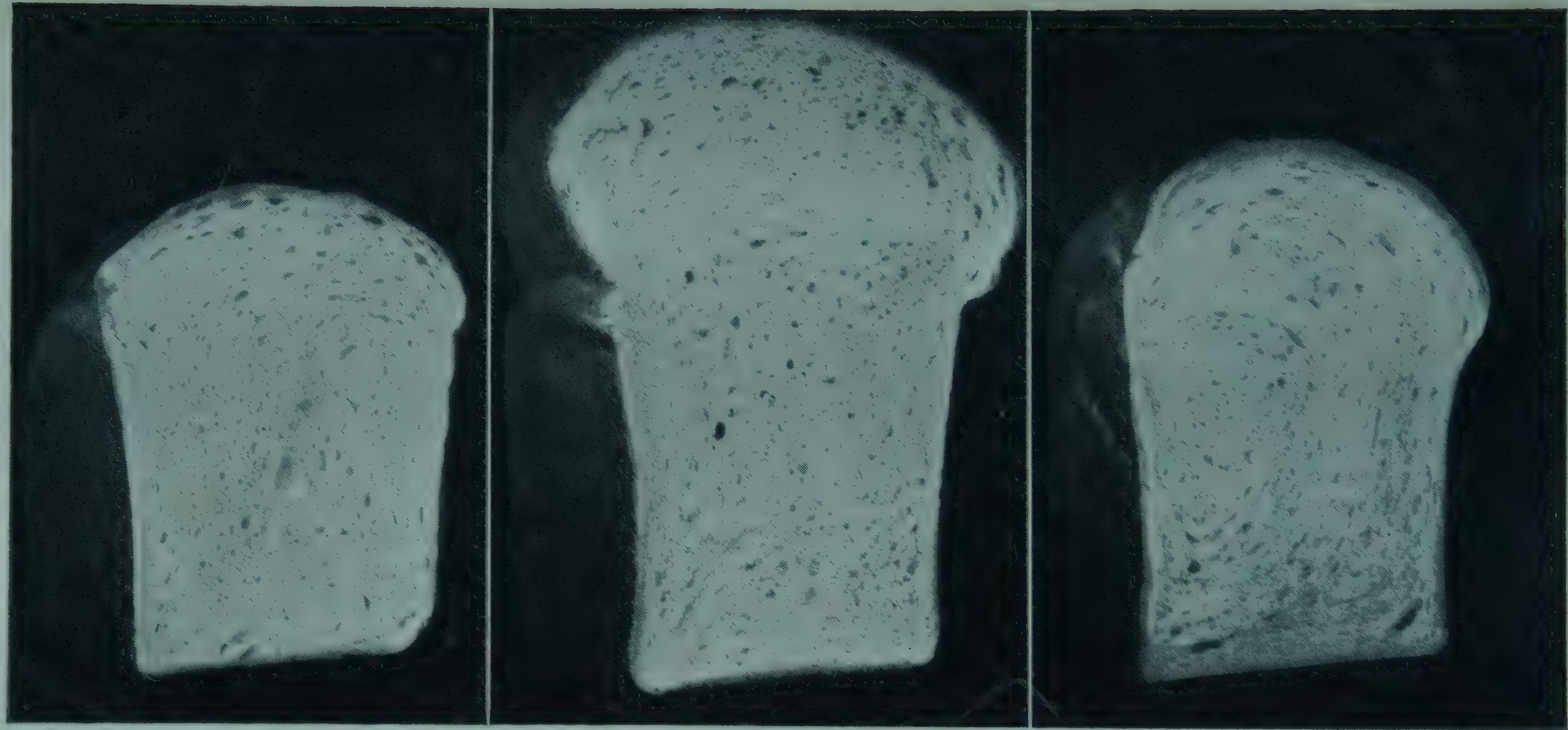
In recent years the following agents have been used:

Improving.	Bleaching.	Improving and bleaching combined.
Ammonium persulphate (solid)	Nitrogen peroxide (gas)	Chlorine (gas)
Potassium bromate (solid)	Benzoyl peroxide (solid)	Nitrogen trichloride (agene) (gas)
Acid calcium phosphate (solid)		Chlorine dioxide (gas)
Ascorbic acid (solid)		

Some of these substances, notably potassium bromate, have been used not only by the miller but to a considerable extent by the baker. Theoretically, the miller is in a position to add all that is needed, but in practice he adjusts the addition he makes in order to take into account the probable amount added by his baker customers.

Improvers increase the tolerance of the dough, i.e., good bread can be made with a wider range of conditions of fermentation, yeast content, etc. They also give a dough which is much easier to handle, particularly in the large plant bakeries. Improvers therefore not only give better bread, but they also help the baker in his normal operations. They must, however, be used with precision, since overtreatment of the flour lowers the quality of the bread. There is in fact an optimum treatment (cf. Fig. 18); the following are representative figures for the more common improvers and bleachers when used on an 80%-extraction flour:[2]

	Optimum addition, p.p.m.
Nitrogen trichloride	60
Chlorine dioxide	30
Benzoyl peroxide	15–45
Potassium bromate	20
Ascorbic acid	20–80
Ammonium persulphate	160



No treatment. Normal improver treatment. Over-treatment.

FIG. 18.—The effects of improver treatment on bread quality.

Acid calcium phosphate and chlorine require higher levels of treatment, viz., approximately 1 lb. and 3 oz. per sack of 280 lb. of flour respectively.

As the extraction of the flour is lowered, less improver treatment is needed. For example, a 70%-extraction flour requires about half the above amounts. On the whole, millers prefer gaseous to solid improvers, for the simple reason that it is easier to incorporate them uniformly in the flour; with solid or powder improvers there is always the risk of small pockets of over-treated flour. This is the reason why nitrogen trichloride or agene, which both improves and bleaches, became so popular not only in this country but also in the U.S.A. and Scandinavia.

Ascorbic acid (vitamin C) is not generally used in commercial practice, but it is a satisfactory improver,[3, 4] although the amounts required demand greater control, since they vary with the type of flour, the range being 20–80 p.p.m. It has no bleaching action. Its activity as a vitamin, wherein lies its appeal, is, in fact, completely destroyed during the baking process.

Physical Methods of Improvement

Inevitably, attempts have been made to achieve improving and bleaching action by physical methods, i.e., without the use of chemicals. For the most part these have consisted of some form of heat treatment.[5, 6] If flour or wheat is heated drastically it will not bake into a loaf. However, by controlling the temperature, the time of exposure and the moisture content of the flour, it is possible to heat flour without damaging it and in fact to improve its bread-making quality. Very roughly, the critical curve of heat treatment corresponds to that above which the germination capacity of wheat is destroyed,[7] suggesting that heat damage takes the form of heat denaturation of the gluten and certain enzyme systems. If the heat treatment is controlled, the dough made from such flour is firmer and easier to handle and the bread has a finer cell structure. There is, however, no significant increase in volume of the loaf, so that the

bread is not so smooth and soft to the touch and the palate as bread made from flour which has been stored for very long periods or which has been correctly treated with a chemical improver. Likewise there is no improvement in the colour of the bread.[8] A suggested alternative to heating the whole of the flour is to heat a portion (*circa* 1%) to a higher temperature, e.g., 180° F. for six hours, and then to mix it with the untreated flour. It has also been shown [9] that any beneficial effects of heat treatment are due largely to the heat inactivation of certain constituents of the germ. Accordingly, another alternative is merely to heat the low-grade flour streams * which contain the bulk of the germ. Heat treatment, however, would appear to be an inadequate and unsatisfactory practical substitute for chemical improvers.

Another form of physical improvement is merely to extend the time of fermentation. If the normal two- to four-hour fermentation time is increased to seven hours, bread is produced equal in all respects to that made from a flour treated with a chemical improver. Halton [10] has explained this on the basis that the all-important physical condition of the gluten is modified not only by the chemical changes that occur during fermentation but also by the continuous working and stretching of the dough resulting from the carbon dioxide generated in it. Unfortunately, under modern conditions it is apparently not a practical proposition generally to extend the time of fermentation to as long as seven hours.

Recently a new process—the "aeration" process—has received much attention.[11] Briefly, a quantity of flour is whipped with water at high speeds for a few minutes. During this period sufficient oxygen is taken from the air to produce a batter which, when mixed with the same quantity of dry flour and made up into bread in the usual way, acts as an oxidising agent not only to improve the bread but also to bleach it. The bleaching effect is due to the activity of the lipoxidase enzyme normally present in germ; if the amount of lipoxidase is too small, as in the case of low-

* See above, pp. 49–52.

extraction flours, a small quantity of soya-bean flour—approximately ¼ lb. per sack of 280 lb. of flour—which is rich in the enzyme, may be added. The improving effect is due partly to the mechanical action of the beating but mainly to an oxidation process which is probably also aided by the lipoxidase present. It is claimed that this process gives bread comparable in colour and crumb quality to that which has been treated with agene or chlorine dioxide.

The same effect can be produced, without a batter fraction, merely by "overmixing" the dough, i.e., mixing it for three to four times the normal mixing time. The extra mixing brings the dough into contact with oxygen from the air for a longer time. Mixing in an atmosphere richer in oxygen would reduce the mixing time required for optimum improving and bleaching.[12, 13]

The aeration process is now being studied extensively in a number of commercial bakeries in tests arranged by the Ministry of Food.

The Mechanism of Improving Action

The action of the bleaching agents would appear to be straightforward. They are all powerful oxidisers, they have no significant effect on the bran pigments, and their function is to oxidise the fat-soluble xanthophyll pigments into colourless compounds; the petrol ether-soluble fraction of flour that has been treated with agene or chlorine dioxide is much lighter in colour than the fraction from untreated flour.

The improving agents, apart from those which also have a bleaching action, are also oxidisers. The apparent exception is ascorbic acid. It is, however, believed that this is first oxidised to dehydro-ascorbic acid and then acts as an improver by handing on oxygen to the dough, itself being reduced again to ascorbic acid. Dehydro-ascorbic acid itself is a good improver.[4]

The chemical changes involved in improvement are still not understood. Improving agents all make the dough more rigid and elastic, whereas certain reducing agents,

such as glutathione and cysteine, have the opposite effect, making the dough softer and less elastic.[14] On the other hand, whereas cysteine has little effect on bread quality, glutathione has a marked effect. Fig. 19 shows the result of adding 200 p.p.m. of gluathione to flour. Flour, and particularly high-extraction flours relatively rich in germ,

FIG. 19.—Normal bread, and (right) bread containing 200 p.p.m. glutathione.

contain an appreciable amount of glutathione; the theory generally held is that improving agents act by oxidation of the sulphydryl groups present in glutathione and in the flour proteins. While the main emphasis has been placed on the role of the –SH groups, the possibility of other reducing systems being involved cannot be excluded. The mechanism of the actual oxidation is equally uncertain. It may proceed directly by molecular oxygen, either through the

intervention of enzyme systems or by a non-enzymatic process. Alternatively—and recent work would favour this view—it may proceed by a linked, indirect mechanism of oxygen transfer, for example, from a lipoid peroxide. Thus it can be shown that methionine in contact with a fat peroxide picks up oxygen from the peroxide to form the sulphoxide and ultimately the sulphone.

The more powerful improving agents, such as agene and chlorine dioxide, act directly and immediately on the dry flour. The others—e.g., potassium bromate, ammonium persulphate and ascorbic acid—act more slowly in the dough stage. It is believed that in addition to any oxidation sequence these improvers affect the papain group of proteolytic enzymes present in the germ.[15] The argument for this is indirect. Both potassium bromate and potassium iodate affect the activity of these enzymes and function as bread improvers. On the other hand, potassium chlorate, which has no action on the enzymes, has no improving action on bread. In a recent paper, however,[16] this theory has been challenged on the grounds that the proteolytic enzymes of wheat flour are not papainases.

Improving agents do not affect the rate of CO_2 production in a fermenting dough, but by making the dough more elastic they increase gas retention, thus resulting in a better rising of the dough in the oven. This increase in volume with 80%-extraction flour is about 15–20%. For the same reason, improver treatment gives more and smaller gas cells with thinner cell walls. The colour of the crumb is thus improved by virtue of its greater light-reflecting power, and in the mouth and to the touch it feels softer and more silky.

The true water absorption of a flour is not affected by improver treatment, but the softer, more sticky nature of an untreated dough would lead a baker to add a little less water, although this would not give him better bread.

The Hazard to Health

Inevitably the addition of chemicals, some of them highly reactive, even in such small amounts, has periodically raised

the question as to how far they involve any risk to health. The first important landmark in this controversy was the setting up of a Committee by the Minister of Health in 1923 with the following terms of reference:

> "Whether and to what extent the practice of treating flour with chemical substances is objectionable on grounds of health and whether it is desirable in the interests of the public health that the practice should be prohibited or restricted, and in the latter case what restrictions should be imposed."

This Committee, under the Chairmanship of Sir Horace Munro, was a powerful one, and included Professor Gowland Hopkins and Professor W. E. Dixon, the eminent pharmacologist. Its Report, published in 1927,[17] might be regarded as a classic in scientific insight and prescience. The conclusions read as follows:

> "In conclusion, while we consider that a staple and indispensable foodstuff such as flour, the purity and wholesomeness of which are of cardinal importance to the community, should be jealously guarded against unnecessary treatment with foreign substances, we are not prepared, on the present knowledge available, to recommend the complete elimination of the bleaching agents and improvers now in use. Our view is that in the first instance it should suffice to limit the use of these substances to those which appear least open to objection when judged along the lines we have indicated. We think that chlorine, nitrogen trichloride and benzoyl peroxide should not be amongst these.
>
> "We have been impressed by the evidence which we have received at a late stage in our enquiry in regard to the possibilities of improving flour by physical rather than chemical methods and by the success which has already attended experiments on these lines on a commercial scale. If improving is necessary, it is in this direction rather than in the use of chemical substances that we should like to see progress made."

The premonition of the Committee with regard to work on nitrogen trichloride twenty years later * is astonishing. Equally, their preference for a satisfactory physical method of improvement follows current medical opinion. At the same time they were not opposed in principle to the use of improving and bleaching agents, and this considered view has persisted. When the Medical Research Council, for example, in 1941 published its specification for National flour it included the following paragraph:

> "The addition of certain 'improvers' to bread baked from flour of high extraction facilitates the work of the baker and results in a more attractive loaf. Such evidence as is available does not justify at this stage the prohibition of their use in the baking industry and the question has therefore been left open."

The 1927 Report contains several penetrating remarks concerning the freedom from any toxic hazard of a particular improver. Thus it criticises chlorine, one reason being that it may enter the tyrosine grouping in the gluten complex. We now know, in fact, that it does produce mono- and dichlortyrosine. The Report goes on:

> "It may be urged that the amount of chlorine used is relatively so small that any changes which may be produced in the flour must be small too and for practical purposes may be disregarded. This, however, is a dangerous argument. We know that foodstuffs contain substances which may be present in very small amounts but are of the highest importance for proper nutrition. We know that those substances are very susceptible to mere traces of chemical reagents which may alter or destroy them and so irremediably impair the nutritive value of the food which contained them. An obvious method of investigating the presence of harmful compounds or suspected impairment of nutritive properties is by feeding experiments with animals. When such experiments give positive results, they are conclusive, but negative results cannot be

* See below, p. 94.

regarded as proof that the material tested is certainly innocuous or that its nutritive properties have not been damaged in some subtle but important respect. The results obtained by feeding experiments are merely the summation of a long series of subtle metabolic changes which by themselves elude our present imperfect methods of detection. It is quite possible that the composition of a food material might be so altered in an adverse direction that although the body would be capable of dealing with it, an extra strain would be imposed upon the tissues and cells of the body which they should not be called upon to bear. The tissues of the body possess marked powers of adaptation to adverse circumstances and exercise their adaptability in dealing with deleterious materials, but it is not desirable to tax this adaptability without necessity.

"Similarly, in regard to another aspect of the problem, namely, the detection of impairment of nutritive properties of a food, it may be remarked that whilst feeding experiments properly conducted may give evidence of relatively gross impairment of nutritive value, it is conceivable that impairments may occur which are not readily detectable by this means."

The Report makes this comment on persulphates:

"They are used as improvers, and on decomposition leave only a small quantity of mineral matter, ammonium or potassium sulphate, in the flour. This, from its nature and small amount can hardly be regarded as harmful."

It did not consider potassium bromate, but presumably this would have been equally acceptable.

No action was taken by the Government on the 1927 Report, and from then onwards the most striking development was the progressive popularity of nitrogen trichloride, or agene, as an improving and bleaching agent, until by the end of the last War more than 90% of the bread flour in this country was treated in this way. It was in 1946 that Mellanby found that flour so treated could produce hysteria in dogs. For many years he had been carrying out

nutritional research on dogs, and had been mystified by recurring fits in these experimental animals. It was in his search for an explanation of the fits that he was led to compare untreated flour with flour treated with agene. This simple differential experiment made history.

Several laboratories in this country and the U.S.A. at once proceeded to investigate the problem with the object of identifying the causative agent. The Cereals Research Station at St. Albans, the laboratories of the British milling industry, were particularly active in the work, and progress reports were published at intervals by a team of workers. Chronologically their findings were as follows:

(i) That (*a*) Canine hysteria (of the type observed in Mellanby's experiments) was not due to any vitamin deficiency, e.g., of pyridoxin, but caused by a toxic factor formed by the interaction of flour protein and nitrogen trichloride (NCl_3). (*b*) The factor was produced with other proteins, including casein, zein and gelatin. (*c*) The reactive amino-acid residue in these proteins was not lysine, tryptophane or glycine.[18a]

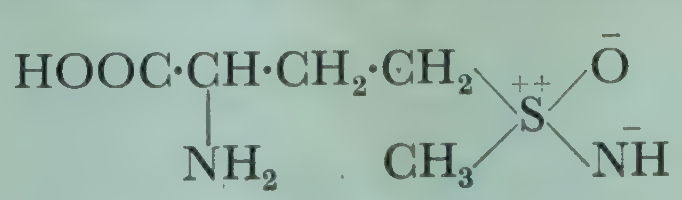
(ii) That the toxic factor was produced by the interaction of nitrogen trichloride and the methionine residue in protein.[18b]

(iii) That the toxic factor resisted boiling for three hours in 8N-HCl. This was the key step in its subsequent isolation. By means of solvent extraction, acid hydrolysis, electrodialysis and ion exchange columns the toxic factor was concentrated 2,500 times.[18c]

(iv) Isolation of the pure toxic factor from zein treated with nitrogen trichloride as needle-like crystals.[18d]

(v) Identification of the toxic factor as a derivative of methionine with the empirical formula of $C_5H_{12}N_2SO_3$.[18e]

(vi) Synthesis of the toxic factor from methionine,[18f] from which it was shown to have the structure



The methods of isolation and synthesis were later published in detail.[19, 20]

The chemistry of the toxic factor—named methionine sulphoximine—was later confirmed by other workers. It is remarkable that, although a small and relatively simple molecule, it was new to organic chemists.

Side by side with the investigation on the isolation of the toxic factor, work was also carried out at the Cereals Research Station on the toxicity of the factor to acid-producing bacteria,[21, 22, 23] which was of considerable value in assessing the usefulness of different procedures in concentrating the factor. Touching on the possible mechanism of the toxic factor in producing hysteria in animals, it was also shown, using an extract of sheep's brain, that the factor interfered with certain enzyme systems involving glutamine.[24]

Further work in this country and the U.S.A. has shown that the sulphoximine, in sufficient amount, is toxic to most, if not all animals (cf. Table 1).

TABLE 1

Critical Toxic Doses of Methionine Sulphoximine

Species.	Dose, mgm./kgm.
Rabbits (orally)	1–2
Ferrets	2
Dogs	3–5
Mice	150–200
,, (by injection)	40
Rats	250
Monkeys (injection)	300–500

Flour treated with the normal commercial dose of nitrogen trichloride contains about 2 p.p.m. of the sulphoximine. On this basis the average total amount consumed by man in one year is 2·5 mgm./kgm.[25] Even assuming no excretion or destruction of the sulphoximine, it would take man 160 years to build up the dose which is toxic to monkeys. This may be the explanation why there is no evidence that agenised flour in the normal diet of man is harmful. Recently, however, a case has been reported [26] of a woman

suffering for many years from a form of dermatitis who is free from any symptoms of the disease when she eats untreated flour but who at once reacts to flour treated with agene or chlorine dioxide. The Medical Research Council is now carrying out further investigations to discover whether this case can be regarded as unique or as evidence in the general controversy on improvers.

Following Mellanby's discovery, the U.S.A. and Canada in 1950 abandoned the use of agene and replaced it by chlorine dioxide. This is a satisfactory improver and bleacher, and the optimum addition to flour is about half that of agene. Furthermore, extensive tests, particularly in the U.S.A., had not shown that it was harmful to any animal. Nevertheless, the milling industry in this country hesitated to make the change-over until further work had been carried out on its action on flour. A first report on this work [27] has shown that traces of modified amino-acids are formed, but none of these so far identified has any toxic properties. Moreover, the action of the gas on the fat in flour is similar to that which takes place in the long storage of flour. The only significant change is a considerable reduction in the vitamin-E content of flour. How far this is of any importance in human nutrition is not yet clear, but again extensive experiments on animals, sponsored by the Medical Research Council, are now in progress to ascertain whether the treatment of flour with chlorine dioxide and other improvers has any effects on reproduction.

As a continuation of the study of the effect of chlorine dioxide on the constituents of flour, further work has been carried out on the tocopherols of flour and bread.[28] The content of α- and β-tocopherol in untreated freshly milled flour, untreated flour twelve months old, a flour powder prepared by spray-drying a well-aerated flour-water batter, and flour treated with chlorine dioxide, have been compared, with the results shown in Table 2. It should be noted that Engel [29] investigated the action of agene and benzoyl peroxide on flour and found that there was a considerable loss of the tocopherols.

TABLE 2

μgm./100 gm. (on a moisture-free basis)

	Untreated fresh flour.	Untreated flour 12 months old.	Aerated (spray-dried) flour.	Flour treated with ClO_2.
α-Tocopherol .	850	600	380	90
β-Tocopherol .	430	380	390	70

(β-tocopherol is considered to have 30% of the biological activity of α-tocopherol.)

The tocopherol content of bread has been compared with that of the flour used in making the bread, and a loss in the bread-making process has been observed. At present it is not known whether this is due to a destructive process or whether some combination occurs during panary fermentation and baking. Data obtained for flour and bread are given in Table 3.

TABLE 3

μgm./100 gm. (on a moisture-free basis)

	Untreated flour.	Bread from untreated flour.
α-Tocopherol .	908	586
β-Tocopherol .	526	155

Thus bread made from untreated (freshly-milled) flour has about 60% of the vitamin E of the flour from which it is made. Bread made from flour treated with a powerful oxidising agent such as agene, chlorine dioxide or benzoyl peroxide contains much less vitamin E. It is, however, important to know the nature of the products formed when the tocopherols of flour are oxidised, whether by atmospheric oxygen or by agents such as chlorine dioxide. This question is being further investigated at the Cereals Research Station.

The whole question of flour improvers is being examined very critically by Government scientists and medical officers

in close co-operation with the Research Associations of the milling and baking industries. Their decisions will be based on actual experimental work designed to give direct answers to the questions involved; they will not be reached on a basis of opinion or prejudice.

Apart from chemical improvers, other additions to flour may be made by the baker. These include substances with surface-active properties, such as glyceryl monostearate, stearyl tartrate and polyoxyethylene stearate, which have the effect of softening the crumb and countering the effects of staling. Originally developed in the U.S.A., they are now, particularly the first, used extensively in this country. It is claimed that the monostearate is free from any toxic hazard and it is in fact said to be present in certain natural fats.[30] There is, however, not the same confidence on the harmlessness of polyoxyethylene stearate, and recently it was prohibited in the U.S.A.[31] Frazer,[32] having in mind the possibility of their accumulation in the body, has called for further research on all three substances.

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CHAPTER SIX

THE DIGESTION AND ASSIMILATION OF BREAD

THE DIGESTION OF BREAD

In the late eighteenth century the Italian naturalist Spallanzani [1] described how he had swallowed a cloth bag containing bread. When the bag had been recovered a day later, the bread had disappeared. The bread had been "digested" during its passage through the gastro-intestinal (digestive) tract, and had been "absorbed" into the blood-stream.

Digestion is the process whereby the constituents of food are broken down into a form that can be absorbed in the body. It is partly a physical process, and partly a chemical process involving biological catalysts known as "enzymes".

Digestion starts in the mouth. The large masses of food are broken down by the teeth into smaller particles which, with the aid of the tongue and the juices of the mouth (saliva), become a paste-like mass, "the food bolus". Within this bolus the chemical process of food break-down starts. The bolus is swallowed, and the food passes down the oesophagus to the stomach. In the stomach the food is churned into a liquid paste through the action of the muscular stomach walls and the digestive juices produced by the wall of the stomach (gastric juice). This mixed liquid, "gastric chyme", is passed slowly and methodically into the duodenum and small intestines. Digestive juices pour into the duodenum from the pancreas via the pancreatic duct. Bile from the liver enters at the same point and helps to emulsify any fat present. These juices, together with the digestive juices from the walls of the small intestines, the *succus entericus*, complete the break-down of the food into a solution of simple chemical substances from which man can absorb directly his nutritive requirements.

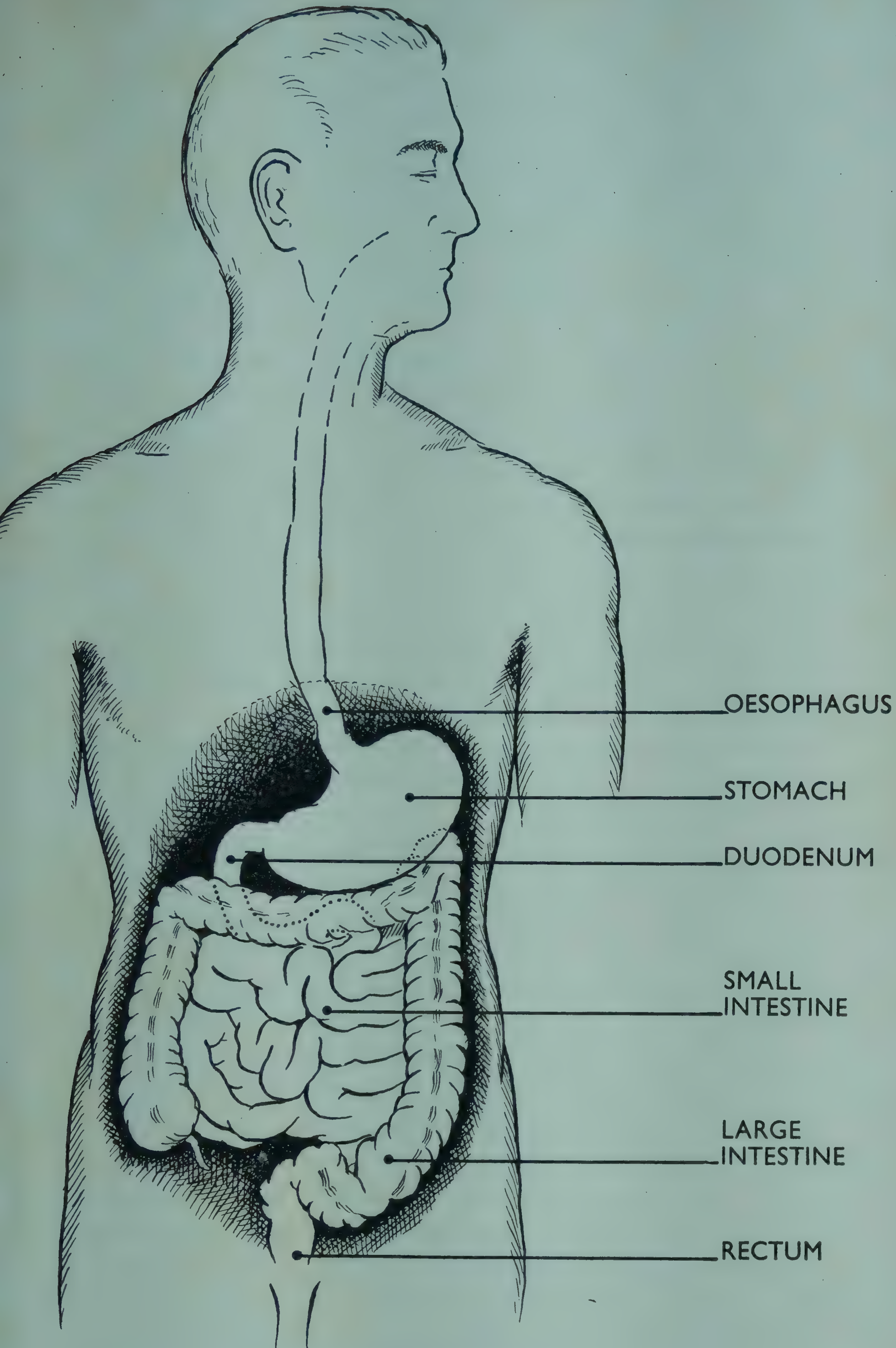

FIG. 20.—The digestive system.

The débris, rough material—mainly cellulose—which has not been affected to any great extent by the physical or chemical processes of digestion, is carried on by the flow of liquid into the large intestines. Here the water content is reduced, and a concentrated paste (faeces), consisting of food residue, bacteria and desquamated epithelium (cells from the digestive tract), is passed from the body in the form of stools.

It is convenient to divide the principal constituents of food into three main classes, namely, carbohydrates, proteins and fats, when considering the chemical process of digestion. Bread consists of approximately 53% carbohydrate, 8% protein, 1% fat and 38% water, together with vitamins and mineral salts.

Carbohydrates

Carbohydrates are a group of compounds, having a general chemical formula $C_x(H_2O)_y$, which includes starches and cellulose (polysaccharides), cane or beet sugar and maltose (disaccharides), and glucose (monosaccharides). It is only in the form of monosaccharides that carbohydrates can be absorbed from the digestive tract and used by man.

The process of digestion of the starch fraction of bread involves the break-down of the large starch molecules into the small monosaccharide molecules of glucose by the starch-splitting enzymes known as amylases. The intermediate stages of this break-down are dextrins and maltose. The final break-down of maltose into glucose is brought about by the disaccharide-splitting enzyme known as maltase.

The digestion of the bread carbohydrate starts in the mouth. In the early nineteenth century the presence of an amylase in saliva was unsuspected. Saliva was considered to act solely as a lubricant, its presence merely enabling a bolus to be formed. It was, however, known that the amount of saliva produced depended on the type of food taken. Thus in 1825 Lassaigne [2] reported that 100 parts of bread crumb produced 30 parts of saliva, whereas 100 parts of bread crust produced 120 parts of saliva. Pavlov in 1902 [3]

showed that in the dog moist bread produced a smaller flow of saliva than dry bread.

The problem in man is complex because saliva flow is brought about not only by the presence of food in the mouth, but also by the thought of food (appetite juice). In this respect appetising foods produce a greater secretion of saliva than unappetising foods. It is probable that the same applies to the production of the other digestive juices throughout the digestive tract.

In some animals lubrication and bolus formation are the only functions of saliva. In man saliva contains the salivary amylase ptyalin which starts the break-down of the starch into the smaller dextrin and maltose molecules. Luciani in 1913 [4] stated that bread starch was partially digested by saliva in the mouth, but that this digestion ceased when the food reached the stomach owing to the destruction of the enzyme by the acid medium found in the stomach. It was later realised, however, that time was required for the penetration of a well-chewed food bolus by the acid stomach juices and that until this occurred the action of salivary amylase would continue.

Bergeim in 1926 [5] showed that the principal activity of salivary amylase took place in the food bolus in the fifteen to thirty minutes after its entry into the stomach. During this time about 59% of the bread starch was converted into maltose; and the activity only came to an end when the food bolus had been completely penetrated by the acid stomach (gastric) juice.

Salivary amylase retains its activity when diluted. Graetz (1945) [6] found that amylase diluted with fifty times its volume of water still possessed a rapid digestive activity little different from that of undiluted saliva. He also showed that cooked wheat starch—as in bread—was more easily digested than starch from cooked potato or maize.

It appears that amylase, if it is to perform its digestive function, must be absorbed at the surface of the starch particle; in wheat starch the particles are sufficiently accessible to allow easy contact between starch and amylase.

The process of baking bread so alters the form of the starch particle as to permit this interaction to a greater extent.

The digestion of carbohydrates is resumed further down the digestive tract. In the duodenum the food comes into contact with pancreatic juice containing pancreatic amylase. In 1909 London and Polowzow [7] showed that in a dog two-thirds of the undigested bread starch leaving the stomach had been broken down before the food reached the end of the duodenum.

The maltose produced by the action of salivary and pancreatic amylases is further broken down to the monosaccharide glucose by the action of enzyme maltase present in the pancreatic juice and of the *succus entericus* of the small intestines. It is in the form of the monosaccharide glucose that bread starch is absorbed into the body.

The relative parts played by salivary and pancreatic amylase in the digestion of bread depend on the degree of mastication and whether or not the type of bread acts as a good stimulus to the production of saliva. O'Rourke in 1951 [8] reported that, in the case of thoroughly masticated bread, up to 75% of the starch might be digested by the activity of salivary amylase in the food bolus, leaving relatively little to be digested by the pancreatic juice. The type and age of bread are important in that they decide the amount of chewing and the rate at which saliva is mixed with the bread. Fresh and soft breads are difficult to masticate properly, whereas dry bread is easily masticated and rapidly absorbs saliva.

However, it appears likely that practically all the starch available to the action of the digestive enzymes has been broken down to glucose and absorbed before the bread reaches the end of the small intestines.[7]

No enzymes are present in man to break down the polysaccharide cellulose. The bulk of the crude fibre of wheat therefore passes through the digestive tract unchanged, and may prevent the digestion of any starch and protein enclosed in it.

Heupke *et al.* (1944) [9] showed that a man consuming

bread made from coarsely ground grain passed larger stools than one consuming bread made from fine flour. Hoppert and Clark (1945),[10] on the other hand, reported that the bulk of stools is not always proportional to the crude fibre or cellulose content of food. The addition of amylase extract to coarse grain may in certain cases increase its digestion and utilisation.

Black bread of 98% extraction is poorly utilised, and faeces collected after eating such coarse breads contain a large residue of material due to poor carbohydrate digestion. In 1944 Trémolières and Erfmann,[11] however, showed that after the addition of amylase extracts the utilisation was comparable with that of white bread.

Proteins

Proteins are complex chemical substances forming the basis of living animal tissue. They are composed of a large number of amino-acid units joined together by peptide linkages. The process of protein digestion severs these peptide linkages and breaks the proteins down into the individual amino-acids. In this form they are absorbed into the body to be rebuilt into body proteins with different structures from the food proteins.

The enzymatic digestion of the proteins in bread does not begin until the food reaches the stomach. There, the gastric proteolytic enzyme pepsin acting in an acid medium starts the break-down of the complex protein molecules. In the duodenum and intestine the food is acted upon by the pancreatic proteolytic enzyme trypsin and the enzymes of the *succus entericus*—known collectively as erepsin—which break the protein molecules down to their amino-acid units. In this form they are absorbed into the body.

Gastric digestion, and especially the presence of hydrochloric acid in the gastric juice, has for long been of interest. For one thing, the stomach lends itself to physiological investigation, and its acid contents can be easily sampled and assessed by means of a stomach tube, or, more directly, by surgical incision through the abdominal wall. More-

over, ailments like ulcers and simple indigestion have encouraged research in this field.

The most famous example of a direct study of gastric digestion was that reported in 1833 by Beaumont, an army surgeon serving in Canada.[12] St. Martin, a tribal Indian attached to the French army in Quebec, had received a gunshot wound which had made an opening in the walls of his abdomen and stomach. The hole healed as a permanent orifice or fistula, and through it Beaumont was able to observe and to sample the contents of the stomach. He noted that when bread was eaten, at the beginning of gastric digestion it took the form of a compact food bolus made up of saliva and large particles of bread; and the gastric chyme which represented the final stage of gastric digestion consisted of a liquid in which the bread had partly dissolved and partly disintegrated into fine particles.

This type of experiment, rarely practicable in man, has been repeated frequently on dogs. Pavlov [3] constructed a pouch or exposed sac of the stomach wall by operative surgery. By this means he was able to determine the amount and composition of gastric juice secreted in response to certain foods. He found that the pepsin secreted after the consumption of bread was five times as plentiful as that secreted in response to milk containing the same quantity of protein. The total acid secreted was, however, much less in the case of bread. The total quantity of juice secreted was slightly larger for bread than for milk and was distributed over a longer period of time.

Pavlov also found that dry bread excited a smaller secretion of juice and passed through the stomach more rapidly than moist fresh bread.

London and Polowzow,[7] modifying Pavlov's procedure, devised tubes to collect and measure the gastric juice produced when 200 gm. of bread were fed to a dog. A total of 325 gm. of gastric juice was secreted. Secretion began about ten minutes after the bread was eaten and continued steadily for five hours. The chyme consisted of gastric juice, saliva and minute particles of bread suspended in a

liquid containing about 32% of the bread in solution. It was sent on to the duodenum in small, periodic squirts of liquid, about 33% passing in the first hour, 18%, 30% and 5%, respectively, in the next three hours, and 4% per hour thereafter until the stomach was empty.

The findings of Pavlov and of London and Polowzow have on the whole been confirmed by later workers, and only one new fact seems to have emerged. Solovyev (1950),[13] using histamine as his standard stimulus to initiate gastric secretion, discovered that bread, unlike histamine, caused more juice to be secreted by the wall of the lesser curvature of a dog's stomach than by the wall of the greater curvature. He held this to account for the lower acid content of chyme resulting from a meal of bread than from histamine.

Two other methods, in addition to the use of fistulae, have been employed to study the gastric contents. Tiedemann and Gmelin in 1826[14] examined the stomach contents of dogs and cats at various intervals after meals of bread and other foods. They reported that the protein fraction of bread was largely digested " in the acids of the stomach " without indicating whether they had tested the protein and starch fractions of flour separately, *in vitro*, in plain acid. A stomach tube was used in 1871 by Meyer[15] to sample periodically the gastric contents of a man who had eaten a meal of 100 gm. of bread. He reported that in two hours forty minutes the stomach had passed all the bread to the duodenum as chyme, and that the total amount of acid produced was the equivalent of 80 ml. of N/10 hydrochloric acid.

The standard clinical techniques used to test gastric function follow the pattern of Meyer's experiment, and in this connection only two other findings need be mentioned. Most foods stimulate the stomach to secrete in a quantitative fashion; the more plentiful the food, the more plentiful the juice. However, Kestner and Warburg in 1923[16] stated that, in the case of bread, no such proportional stimulus occurred after the ingestion of an initial amount of bread. Zoethout (1931)[17] went further, and declared that bread, as such, exerted no chemical stimulus on the secretion of

gastric juice and that the resulting gastric juice had, therefore, the minimum content of digestive reagents.

One may infer that only a weak digestive solution is produced in the stomach when bread is ingested as a pure food. In effect, dry bread is easily reduced to a semi-liquid state, and for the most part rapidly passed on to the duodenum, whereas fresh, moist bread requires longer for its passage through the stomach, because it resists conversion to chyme. The latter event, indeed, may cause mild indigestion in man.

Pavlov [3] found that bread alone is a poor stimulus for the production of pancreatic juice, giving rise to a very dilute juice compared with that produced by milk and meat. Sampling the contents of a dog's small intestine by means of a jejunal fistula, he noted also that buttered bread was digested more rapidly than plain, perhaps because butter stimulated the pancreas to fuller secretion.

Lehman and Gibson (1924) [18] observed by means of a jejunal fistula that soft bread in particular frequently left the stomach in a poorly digested state, its protein untouched, and passed the fistula little changed. London and Polowzow [7] had, however, found no undigested protein remaining by the time the bread given to a dog had reached the end of the small intestines.

In vitro experiments by Yenson (1946) [19] on wheat demonstrated that the protein was digested slowly by pepsin and even more slowly by trypsin. Both enzymes showed poor activity when tested on wheat proteins subjected to strong heat—200° C.—or hot frying. Booth and Moran (1946),[20] working on wheat bran, found that a similar reduction in digestibility resulted when the bran was baked into biscuits. *In vitro* tests with pepsin and trypsin showed that about 60% and 75% respectively of the protein of uncooked bran was digested, but after baking only 45% and 70%. That only three-quarters of the protein in uncooked bran—two-thirds if the bran is not finely ground—is digested by these enzymes *in vitro* has also been shown by Bigwood (1948),[21] who worked on the ether-extracted residues of wheat bran. Mild heat

treatment of wheat protein was found by Liener (1950)[22] to increase the extent of tryptic digestion slightly, by inactivating factors which inhibited the action of trypsin.

One may conclude that the proteins of bread (and wheat) may not be completely digested by the proteolytic enzymes of the gut when bread is fed alone—and research has been largely restricted to bread fed as a pure food. The causes are the slow rate at which both pepsin and trypsin act on bread and the poor stimulus afforded by bread to their secretion by the stomach and the pancreas. In a mixed diet, however, where the stimulus is given by other foods, the proteolytic digestion of bread may be assumed to be complete.

Fats

The fats in bread are mainly the esters of glycerol (glycerine) and fatty acids. The fats are broken down into these components by the enzymes known as lipases present in the digestive tract. After absorption, the glycerol and fatty acids, in combination, re-form the fat.

No lipase is present in saliva and little is present in the stomach. The digestion of fat does not make much progress until the food reaches the duodenum. Here the fat is emulsified by the action of the bile salts secreted by the liver, and digested by the lipase secreted by the pancreas. The duodenal contents are alkaline, and the emulsification may be aided by soap formation (soaps being the salts of fatty acids).

Fat is absorbed from the small intestines and enters the blood mainly via the lymphatic system (lacteals).

THE DIGESTIBILITY OF BREAD

Definition

The " digestibility " of a food is the proportion of the food that is absorbed into the body during the passage through the gut. It is usually expressed as a percentage :

$$\text{digestibility } (\%) = \frac{\text{food absorbed}}{\text{food intake}} \times 100 \text{ (Equation 1}$$

The remaining undigested portion of the food passes out in the faeces.

It is difficult to employ the direct method to estimate the amount of food passing through the wall of the digestive tract into the body. Direct analyses of the blood and lymph in the large vessels leading away from the intestines have been made in the rat, and blood analyses from peripheral vessels are easily carried out in man, but the scope of these methods has in the past been too limited to give conclusive results.

Ignoring the slight loss that may arise due to the utilisation of food by the bacteria in the gut, the percentage of food *absorbed* will be equal to the percentage of food *disappearing* during the passage through the digestive tract. The food " disappearing " may be estimated by the indirect method, by comparing the amount of food taken orally and the amount lost in the faeces. Thus :

$$\text{digestibility } (\%) = \frac{\text{food intake} - \text{food residue in faeces}}{\text{food intake}} \times 100 \qquad (2)$$

$$= \left(1 - \frac{\text{food residue in faeces}}{\text{food intake}}\right) \times 100 \quad . \quad . \qquad (3)$$

Carefully controlled experiments on the " digestibility " of bread were carried out as early as 1883 by Rubner,[23] using this method. Bread made from flours of different extractions was used and some highly significant results were recorded. Rubner calculated that in whole-wheat and high-extraction bread much of the carbohydrate associated with the bran escaped absorption in the intestines, only a fifth of the nutrients of bran being absorbed. The absorption of white bread, on the other hand, was most efficient and little material escaped.

" Apparent " and " True " Digestibility

An estimation of digestibility from the amount of faeces formed will give only an " apparent " digestibility. Faeces are derived not only from food residue but also from in-

testinal secretions and the multiplication of bacteria. Thus much of the " food residue " concerned is not the product of ingested food. It is interesting to note that faeces are still formed when no food is taken by mouth, and do not differ markedly in composition from normal faeces.

To save confusion, " digestibility " as defined in Equation (1) is often referred to as " true digestibility ". To obtain a figure approaching " true digestibility " the direct method must be employed or else corrections must be applied to the apparent digestibility obtained by the indirect method. In both cases it is easier to consider the constituents of bread rather than bread as a whole.

Carbohydrates

The digestibility of the carbohydrate fraction of bread can be found directly, since the monosaccharide glucose released by digestion can be estimated with comparative ease in samples from the intestinal juice, intestinal blood vessels and from other blood vessels. The glucose in the blood is known as the " blood sugar ".

Using the technique of periodical blood sampling and analysis of the blood sugar, Kotschneff in 1923 [24] found that two hours after a meal of bread the blood sugar level in the veins leaving the intestines of a rat had increased from 80 mgm. to 260 mgm. per 100 cc. of blood.

More recently, in 1944, Trémolières and Erfmann [11] showed that, in man, a meal of white bread raised the blood sugar to a higher level than one of black bread. They traced the specific cause to differences in availability of the carbohydrate for absorption. The addition of amylase extract to the black bread reduced the difference.

The method of blood sugar analysis was used by Franke (1949),[25] who recorded better carbohydrate digestibility in man from fully leavened bread than from partly leavened bread. Orrù in 1940 [26] employed a modified version of the method in experiments with rats. He noted that the amount of carbohydrate absorbed decreased as the extraction rate of flour (fed as flour) was raised from 68 to 100%.

This reduction in absorption was attributed to irritation of the intestinal surface by the coarser flour. However, variation in the fineness of grind made little difference to the absorption, and a more convincing explanation is that more carbohydrate was present in the higher-extraction flour in the form of relatively indigestible cellulose or fibre.

Indirect measurements of the digestibility of carbohydrate of bread have been made by many workers. From the experiments of Macrae *et al.*,[27] Moran and Pace in 1942 [28] calculated the following digestibilities of flours of different extractions:

% Extraction . .	75	85	90	95	100
% Digestibility . .	97·0	93·9	91·5	88·7	86·3

These figures indicate that the digestibilities of the increments between extraction rates of 85–90%, 90–95% and 95–100% are approximately 50%, 40% and 40%.

Proteins

The digestibility of the protein fraction of bread could theoretically be measured directly by amino-acid estimations in the vessels leaving the intestinal tract. This method has not, however, been found practicable, and the indirect method of faecal analysis of unabsorbed residue is usually employed. Proteins, unlike carbohydrates and fats, contain nitrogen. It is therefore possible to estimate the digestibility of the protein fraction by an analysis of the nitrogen in the food intake and faeces.

Equation (3) now becomes

$$\text{digestibility} = \left(1 - \frac{\text{N residue in faeces}}{\text{N intake}}\right) \times 100 \quad . \qquad (4)$$

Corrections must be applied for the presence of nitrogenous substances in the faeces not derived from the food taken if the true digestibility is required.

Macrae *et al.* (1942) [27] estimated the apparent protein digestibility of whole-wheat bread and white bread in man, and found that the former was less completely digested

than the latter. However, the protein content of whole-wheat bread was higher, giving approximately equal protein absorption for a given weight of bread.

Krebs and Mellanby (1942),[29] after applying a correction factor obtained from a control diet containing no bread, obtained a " true " digestibility, in man, of 94·3% for the dry matter and 89·4% for nitrogen in bread of 85%-extraction rate.

McCance and Widdowson (1947),[30] investigating wheat proteins, found that in man, for 80%- and 90%-extraction bread, apparent digestibility was 83·4% and 80% respectively (see Table 1).

TABLE 1

Apparent Digestibility of Wheat Protein

Type of wheat.	Protein, % per 100 gm. N × 5·7	Nitrogen for 7-day period.		Apparent digesti-bility.
		In food, %	In faeces, %	
English 80%-extraction .	8·1	67	11·2	83·4
English 90%-extraction .	8·3	68	13·6	80·0

McCance and his collaborators made an attempt to determine the difference between apparent and true digestibility in a series of experiments on man, which they reported in 1945,[31] 1947 [30] and 1948.[32] Bread baked from flours extracted at various levels from several wheats was used in the experiments. From their results they concluded that the digestibility of bread was highest in cases of the lower-extraction levels of flour. This confirmed the conclusion reached by Moran and Pace in 1942 [28] that digestibility decreased as the fibre content of the flour increased. Moran and Pace calculated that 0·15% fibre decreased digestibility by 1·1%, but McCance and Walsham in 1948,[32] using more accurate data, reached the conclusion that 0·15% fibre was an underestimate and adopted the factor 0·2% fibre as causing a loss of 1·1% digestibility. Apparent digestibility

was then the digestibility of the bread when this factor was omitted from the calculation, and the values reported revealed that white bread (of 75%-extraction flour), National bread and whole-wheat bread were digestible very closely in inverse proportion to their fibre contents. When these values were recalculated to include the factor, figures closely approximating to true digestibility were obtained. The most dramatic effect was seen when the values for the apparent digestibility of the various constituents of flour were recalculated. Allowing for the fibre content, the digestibility of the protein and carbohydrate in bread appeared to be between 90% and 100%, while the digestibility of fat and purine constituents remained at little more than 60%.

The Effect of Variations in Milling and Baking on Digestibility

The term the "colloid-chemical state" of bread was applied by Heupke in 1941 [33] when describing the effect on digestion of the size of the particles, air spaces, moisture and similar characteristics of bread. He was of the opinion that dry, well-leavened bread, with a sound structure of air spaces, made from finely ground flour baked at a moderate temperature, was more readily digested than moist, poorly leavened bread made from coarse flour. Opinion on the effect on digestibility of the degree of milling of the flour has been divided. Macrae *et al.* (1942),[27] Heupke *et al.* (1944)[9] and Lévy and Jacquot (1948) [34] thought that both wheat flour and pure wheat starch were more easily digested by man and by rats when finely ground than when coarsely ground, and that the residual material in the faeces was much reduced in the former case. Romberg (1897),[35] Lintzel (1944) [36] and Stevens *et al.* (1952),[37] on the other hand, denied that the digestibility of wheat flour was improved by a decreased size of particles in general or by fineness of milling in particular. To decide which opinion is correct is perhaps a matter of personal choice. But certainly, the more finely ground flours produce a bread that is more homogeneous and consistent in texture.

There is sufficient evidence from the work of Penew (1944),[38] Franke (1949) [25] and Amos (1951) [39] to support Heupke's assertion that proper leavening is an aid to digestion in man, although the first of these could find little connection between microscopic appearance and digestibility. The beneficial effect of moderate heat in baking was confirmed by Liener (1950) [22] and Griswold (1951),[40] who discovered that severe heat could seriously damage the proteins of wheat products, whereas moderate heat might even increase the digestibility of both protein and starch fractions of bread. That digestion can occur in uncooked wheat starch and is accelerated by cooking was shown by Graetz (1945) [6] and Huinink (1946).[41]

THE ASSIMILATION OF BREAD

The Utilisation of Carbohydrates, Fats and Proteins

The carbohydrates, fats and to a certain extent the proteins, of bread and other foods in the diet are used by the body as a source of heat and energy. As has been seen, the carbohydrates are absorbed from the digestive tract into the blood-stream as monosaccharides (mainly glucose). The monosaccharides other than glucose are converted into glucose by the liver. The glucose circulating in the body as blood-sugar supplies the tissues with nourishment. Any excess is stored in the liver as animal starch (glycogen) or is converted into fat and stored in the fat depots of the body, e.g., beneath the skin.

1 *gram carbohydrate after absorption provides approximately* 4 *Calories* of energy.*

The small amount of fat in bread, and the fat from the other foods, after absorption are also used as a source of energy; the surplus is stored in the fat depots.

1 *gram fat after absorption provides approximately* 9 *Calories of energy.*

The protein in bread and the rest of the diet, as has been seen, is absorbed as amino-acids. These amino-acids are

* 1 Calorie = 1 kilocalorie = 1000 calories.

needed for the formation of body protein, a process essential for growth and the repair of tissues. Excess amino-acids are broken down, the nitrogen excreted via the kidney in the urine as urea and other nitrogen compounds, and the remainder of the amino-acids utilised as a source of energy; it appears unlikely that any excess are stored as fats.

The energy provided by the protein will depend on the exact amino-acid composition. On the average,

1 *gram protein after absorption provides approximately* 4 *Calories of energy.*

Amino-acids

Although a large number of different proteins exist, only a few amino-acids (say twenty) contribute to their formation. Of these only about eight (the essential amino-acids) are indispensable to adult man, and must be supplied in a preformed state, because man cannot synthesise adequate amounts of them from other nitrogenous sources. Two other amino-acids, arginine and histidine, appear to be essential during growth only.

The essential and non-essential amino-acids are listed in Table 2:[76]

TABLE 2

Essential amino-acids.	Non-essential amino-acids.
Valine	Arginine
Leucine	Histidine
*iso*Leucine	
Threonine	Glycine
Methionine	Alanine
Phenylalanine	Serine
Lysine	Cystine
Tryptophane	Tyrosine
	Aspartic acid
	Glutamic acid
	Proline
	Hydroxy proline
	Citrulline

A continual break-down of tissue protein is taking place in the body, and some nitrogen is excreted in the urine. This must be replaced by proteins in the food. In growth and during pregnancy, additional amounts of proteins are required from the food to build up body proteins.

The amino-acids derived from the food proteins circulate in the blood for a short time after absorption, enabling tissues of the body to take up their requirements. As noted above, the excess are broken down in the liver and the nitrogen removed, a process known as " deamination ". The body appears to have no store of amino-acids, and it is therefore desirable that all the essential amino-acids should be available from the food proteins at each meal. If any of the essential amino-acids are missing or in short supply, utilisation of the remainder to form body proteins may be impossible. If the deficiency occurs repeatedly at each meal, normal growth and tissue repair will cease.

It will be seen that an ideal food contains all the essential amino-acids in approximately the ratio required by the body. An amino-acid deficiency in one food, however, is unimportant if other foods containing the deficient amino-acids are taken at the same time.

The proteins of the endosperm of wheat are relatively deficient in the amino-acid lysine, whereas there is a superfluity of the non-essential amino-acid glutamic acid. The proteins of the germ contain all the essential amino-acids in approximately the correct proportions.

Barton-Wright and Moran [42] give the following table for the distribution of the essential amino-acids in the wheat grain.

TABLE 3

Distribution of Essential Amino-acids in Wheat Protein

(Calculated to 16% N on moisture- and ash-free basis)

Amino-acid.	Inner endo-sperm, %.	Outer endo-sperm, %.	Bran, %.	Germ, %.	Whole wheat, %.
Tryptophane	0·93	1·12	1·83	0·90	1·03
Phenylalanine	3·95	3·43	2·45	2·47	3·68
Lysine	1·92	2·60	3·87	5·44	2·80
Threonine	2·56	2·72	2·85	6·28	2·78
Valine	3·65	4·02	4·10	4·20	4·00
Methionine and cystine	2·67	3·30	2·59	2·65	3·06
Leucine	9·14	7·98	6·52	7·33	8·27
*iso*Leucine	7·02	6·56	4·50	5·23	6·97

It follows that the nutritional value of bread proteins will depend on the extraction rate or, more accurately, on the percentage of each layer present in the flour before baking.

It is of interest to compare the amounts of the essential amino-acids supplied by 50 gm. of white flour protein and 50 gm. of whole egg protein—an excellent example of a well-balanced protein of animal origin.

TABLE 4

Amino-acid.	Daily adult requirement,[43] gm.	Amounts supplied by 50-gm. protein from	
		Whole egg, gm.	White flour, gm.
Tryptophane	0·5	0·75	0·4
Phenylalanine	2·2	3·15	2·75
Lysine	1·6	3·6	0·95
Threonine	1·0	2·45	1·35
Valine	1·6	4·60	1·7
Methionine	2·2	3·25 *	2·4 *
Leucine	2·2	4·60	6·0
*iso*Leucine	1·4	4·0	1·85

* Methionine + cystine.

This comparison confirms that the main amino-acid deficiency of white bread is in lysine.*

The Assessment of Assimilation

Much research has been devoted to comparing the nutritive values of bread made from flours of different extractions, and a summary is given below. However, it must be remembered that the assessment of nutritive value must be related to the criteria used, e.g., the growth of young animals, the maintenance of adult animals, or the regeneration of body protein in depleted animals. It is also affected by the nature of the other foods which are ingested at the same time.

Carbohydrates

Assimilation (%). The term " percentage assimilation " is defined as the percentage of the food intake that is utilised by or incorporated in the body.

* See below, pp. 153, 157–9.

In the case of carbohydrates, unless there is gross vitamin deficiency, all the carbohydrate *absorbed* is used by the body as a source of energy or heat or in the synthesis of body substances, excess being converted to glycogen and fat for storage. The assimilation (%) of carbohydrate is thus equivalent to its digestibility.

Proteins

Assimilation (%). The same is not true of proteins, however. The fact that an amino-acid is absorbed into the blood-stream does not mean that it is necessarily incorporated as body protein. This applies particularly to food proteins containing a poor assortment of amino-acids. Here a large protein intake is necessary to supply the requirements of the amino-acids present in minimal amounts. Consequently other amino-acids may be in excess of body requirements. It follows that proteins, such as those found in the germ of wheat, have a greater value in assimilation than (say) endosperm proteins, which have a poorer ratio of amino-acids, and serve relatively to reduce the total protein requirements of the body.

Expressed as a percentage, the assimilation of the protein of bread becomes

$$\frac{\text{protein retained}}{\text{protein intake}} \times 100 \quad . \quad . \quad . \quad (5)$$

It is more convenient to estimate nitrogen assimilation thus:

$$\begin{aligned} \text{assimilation } (\%) & \\ &= \frac{\text{N retained}}{\text{N intake}} \times 100 \\ &= \frac{\text{N intake} - \text{N excreted in urine}}{\text{N intake}} \times 100 \\ &= \frac{(1 - \text{N excreted in urine})}{\text{N intake}} \times 100 \quad . \quad (6) \end{aligned}$$

Biological Value (*B.V.*). The above assessment of assimilation is necessarily dependent on the digestibility of the

proteins. A truer comparison of proteins is obtained by considering their "biological value". The biological value is that percentage of a protein which *after absorption* is retained and incorporated in the body :

$$\text{biological value } (\%) = \frac{\text{protein retained}}{\text{protein absorbed}} \times 100 \quad . \quad (7)$$

Using nitrogen as an indication, biological value is the percentage of absorbed nitrogen retained by the body.

Biological value (%)

$$= \frac{\text{N retained}}{\text{N absorbed}} \times 100 \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$= \frac{\text{N absorbed} - \text{N excreted in urine}}{\text{N absorbed}} \times 100$$

$$= \frac{(1 - \text{N excreted in urine})}{\text{N absorbed}} \times 100 \quad . \quad (9)$$

It follows from Equations (1), (5) and (7) that, for a given protein,

$$\text{assimilation } (\%) = \text{absorption} \times \text{biological value.}$$

The absolute values obtained for biological value will depend on the animals' protein requirements, and thus on the detailed experimental conditions. In most cases only relative figures obtained under the same conditions are required.

A survey of the data published by Mitchell and Carman (1926),[44] Chick (1942),[45] Macrae *et al.* (1942),[27] Hoagland *et al.* (1945),[46] Hegsted *et al.* (1947),[47] Chick *et al.* (1947),[48] McCance and Walsham (1948),[32] and Takagi *et al.* (1951),[49] indicates that, for the three commonest breads, the figures given in Table 5, column (*a*), are fairly reliable. Henry and Kon (1945),[50] however, give lower figures for whole-wheat bread and 85%-extraction bread under similar conditions. Their figures are given in column (*b*).

Protein Efficiency Ratio (*P.E.R.*). Many methods are employed in the estimation of protein retained. In a growing

TABLE 5

	Biological value, %.	
	(*a*).	(*b*).
Whole-wheat bread	70	56·1
National (85%-extr.) bread	65	53·2
White (70–75%-extr.) bread . . .	52	51·2

(The biological values given are those for a young growing rat with 8% protein in the diet.)

animal the protein retained is incorporated in the body tissues, and the rate of growth will give an indication of the assimilation (%) of the protein considered.

Osborne and Mendel in 1919 [51] established that the various parts of wheat contained different types of protein, some of which could support growth of the young rat better than others. The proteins of bran were superior to those of wheat germ and embryo; moreover, the proteins of the endosperm, if given alone, were of little value in promoting growth.

In this special sense the term protein efficiency ratio (P.E.R.) is used. It is defined by the following equation:

$$\text{P.E.R.} = \frac{\text{wt. increase}}{\text{gm. protein eaten}} \quad . \quad . \quad (10)$$

Experiments on bread have shown that a high-extraction bread gives a better rate of growth than the more completely absorbed white bread. Light and Frey in 1943 [52] recorded the rate of growth of young rats and found that the white (low-extraction) bread that they ate gave a poor rate of growth. The addition of supplements to replace certain deficient constituents (mainly the amino-acids lysine and valine) increased the rate of growth to that given by whole-wheat bread.

The protein efficiency ratio and biological value of the proteins of white bread and whole-wheat bread were determined by Carlson *et al.* in 1946,[53] working with young rats. The results are shown in Table 6.

TABLE 6

Biological Quality of Wheat Proteins of White Bread and Whole-Wheat Bread

Source of dietary protein.	Growth studies.			Biological value from nitrogen balance study with equalised intake.
	Ad libitum intake.	Equalised intake.		
	Protein efficiency ratio.	Protein efficiency ratio.	Body protein gain, gm.	
White bread . .	0·87	0·66	4·2	38·9
Whole-wheat bread .	1·18	0·75	4·2	45·9

Beaty and Fairbanks (1948),[54] Seeley *et al.* (1950) [55] and Engel *et al.* (1951) [56] measured the rate of growth of rats, and concluded that although the protein of white bread had a lower biological value than that of whole-wheat bread, it was more easily absorbed, and was therefore of equivalent value in assimilation. Graves (1946),[57] and Childs and Macrae (1948),[58] on the other hand, asserted that whole-wheat bread was adequately absorbed and that its superior biological value made it more valuable in assimilation.

Nitrogen Balance. An alternative method of estimating the assimilation of the protein of bread is to compare the test food and an arbitrary food standard in maintaining a balance in the total nitrogen ingested and excreted by a fully grown animal.

In 1941 Sealock *et al.*[59] and Murlin *et al.*[60] from preliminary experiments felt justified in assuming that whole egg was virtually 100% assimilated in man and made it their standard. They found that, compared with it, whole-wheat bread was 81% and white bread 90% assimilated.

Chemical Score. In 1946 Block and Mitchell [61] reviewed the extent to which the various proteins of wheat differed from egg protein, which was used as a standard. The amino-acid composition of the protein was analysed and the per-

centage by which an amino-acid differed from that of whole egg protein was called the " chemical score ". The proteins of the endosperm have lower chemical scores than the proteins of bran and embryo owing to a deficiency of lysine and methionine.

TABLE 7

Percentage Deviations of Contents of Amino-acids in Wheat Proteins from those in Whole Egg taken as Standard

Amino-acid.	Percentage deviation from corresponding value for whole-egg proteins.		
	Whole wheat.	Wheat germ.	White flour.
Arginine	−34	− 6	−39
Histidine	9	+19	+ 5
Lysine	−63	−24	−72
Tyrosine	− 2	−16	−16
Phenylalanine	−10	−33	−13
Tryptophane	−20	−33	−33
Cystine	−25	−67	−21
Methionine	−30	−51	−63
Threonine	−33	−22	−45
Leucine	−26	−27	−18
*iso*Leucine	−55	−62	−54
Valine	−38	−44	−42
Amino-acid indicated as limiting	lysine	*iso*leucine	lysine

An indirect test on the assimilation of bread was carried out by Hitchings and Falco in 1946.[62] They tested the resistance of mice to pneumonia when fed on diets of whole-wheat bread and white bread. After feeding for six days on whole-wheat bread adult mice were infected with virulent pneumococcii. Only 2% of the animals in question survived for 1·7 days, but when the experiment was repeated with white bread, 40% survived for 3·7 days.

Net Protein Value (*N.P.V.*). When comparing the overall protein value of one food with that of another, or of one type of bread with that of another, it is necessary to consider not only protein assimilation (i.e., digestibility × biological value), but also the concentration of protein in the food. The latter will determine the amount of food required to provide a given amount of protein in the diet.

The term "net protein value" has been introduced to cover both these aspects of protein intake from the diet. It is defined as the number of grams of protein retained in the body per 100 gm. of food intake. It is thus a measure of the content and nutritive quality of the assimilable protein in the food.

Net protein value (n.p.v.)

$$= \frac{\text{protein retained}}{\text{food intake}} \times 100 \qquad (11)$$

$$= \frac{\text{protein retained}}{\text{protein intake}} \times \frac{\text{protein intake}}{\text{food intake}} \times 100$$

$$= \text{assimilation} \times \text{protein concentration in food} \qquad (12)$$

$$= \text{digestibility} \times \text{biological value} \times \text{protein concentration in food} \qquad (13)$$

The various factors which determine the net protein value of bread proteins at different extraction rates may be summarised as follows:

1. The protein content of the bread decreases as the extraction rate is reduced.
2. The biological value of the bread proteins decreases as the extraction rate is reduced.
3. The digestibility increases as the extraction rate is reduced.

At extraction rates below 80% relatively little bran and wheat germ is present in the flour.

The overall nutritive value of the proteins (net protein value) of bread thus depends on a balance or compromise between their content, their biological value, the extraction rate of the flour and its digestibility. Lintzel in 1944 [36] found that whole-rye bread of high protein content had a lower net protein value than whole-wheat bread of much lower protein content, simply because of its lower digestibility. However, two breads of the same digestibility but different protein content may have widely differing net protein values. This was demonstrated in 1948 by McCance and Walsham,[32] who instanced breads made from Manitoba

hard wheat (of good protein content and high net protein value) and English soft wheat (of lower protein content and low net protein value).

The data available for man is insufficient for an accurate determination of the net protein value of different extraction breads. Table 8, however, gives the net protein value for the rat of wheats of different extraction.[50, 63] It will be seen that the optimum extraction rate is 80–85%. The metabolic requirements of the rat are very similar to those of man, and there is every reason to suppose that the same optimum extraction rate applies to man.

TABLE 8

Extraction rate, %.	Net protein value.
100	5·58
85	5·52
80	5·66
70	5·09

On a good mixed diet the low biological value of the bread proteins (even of those of white bread) is relatively unimportant, since the deficient amino-acids are supplied by the remainder of the diet.

When bread forms the major portion of the diet, the selection of the optimum extraction rate is important; but, however much this may improve the assimilation of the proteins in bread, it cannot wholly compensate for a deficiency of essential amino-acids. The only means of obtaining a significant gain in biological value and satisfying the general requirements of assimilation is to add a protein supplement to the bread.*

Fats

The fat content of bread is low. In some types of wholewheat bread the concentration may reach 2·5%, but the amount absorbed is less, since much of the fat, being contained in the bran fraction of the wheat, is lost with other

* See below, pp. 145, 153.

constituents owing to the poor digestibility of bran. In white bread the concentration is only 0·8%, and the problem of estimating the assimilation ceases to be practicable. Slack in 1948 [64] reported a series of experiments with rats to which he had fed wheat flours of various extractions made into bread. The rats fed on higher-extraction flour showed an increased fat content over those fed on white bread. However, the quantity of bread eaten was not controlled, and, as high-extraction bread is more appetising to the rat than low-extraction bread, Slack concluded that this fat was derived almost entirely from carbohydrate sources rather than the small amount of extra fat in the bread.

Walker (1948) [65] gave mixed diets which contained very large amounts of bread to human subjects. In both low-fat and ordinary diets no change occurred in fat absorption when they changed from bread made from high-extraction flour to bread made from low-extraction flour. One may conclude that the fat present in bread is of a negligible quantity and exerts no dietary influence in such experiments.

FRESH AND STALE BREAD

Zoethout in 1931 [17] and Bartels in 1943 [66] showed that fresh bread which is too moist and insufficiently chewed forms pasty lumps that resist, both *in vivo* and *in vitro*, penetration by gastric and other digestive juices. If the bread is dry, irrespective of its age, these juices are able to penetrate the lumps and effect a high degree of digestion.

The process of staling was said by Heupke in 1941 [33] to improve the colloid-chemical structure by increasing the porous nature of the bread. Unleavened bread, being non-porous, was not improved by staling. In the opinion of Penew [67] and Jackel *et al.*,[68] stale bread, irrespective of its colloid-chemical state, possessed a much greater digestibility than fresh bread, and was handled more rapidly both *in vivo* and *in vitro* by all the stages of digestion. Bartels' *in vitro* studies [66] indicated that the ease of digestion of the carbohydrate and protein in bread depends on changes,

with time, in the colloidal nature of starch-protein complexes in the bread. Staling for five days brought about the most efficient state for protein digestion, but for carbohydrate digestion ten days were required. After these periods there was no improvement in the digestion of the protein and carbohydrates due to staling. Jackel *et al.*[68] found that prolonged staling gradually reversed this increased digestibility.

The effect of storage of the flour before baking into bread is even more remarkable than that of staling. Amos [39] pointed out in a review article in 1951 that freshly milled flour had poor digestibility and bread-making qualities, but that storage for a period of six weeks brought about changes in the gluten that resulted in good elasticity, and consequently in good bread texture.

The process of aging flour has presented a problem to bakers throughout history. Sarton in his *Introduction to the History of Science* [69] refers to the large earthenware pots used in pre-Roman times to store the flour and wheat for long periods in order to age it before baking. In modern times the addition of " improvers " reduces the time required to produce the effects of long storage.* The storage of wheat or flour does not seem to cause any loss in the nutritive value of bread made from them, provided that the conditions of storage are carefully regulated. Fifield and Robertson (1945) [70] examined, in 1939 and again in 1945, wheat stored since 1921 under dry, cool conditions. The only changes they noted were a decrease in the germination quality of the wheat and a small increase in the acidity of the fat; the resulting bread was fairly similar in quality to bread produced from the wheat at the beginning of the experiment. Moran [71] reports that flour stored at about 13% moisture content and free from insect pests will remain in sound condition for six to eight years; beyond this period the fat in the flour, and likewise in bread made from it, becomes unpleasantly rancid.

* See above, p. 84.

TOAST

When bread is toasted, losses in its nutritive value occur. These, however, are of importance only when bread forms the greater part of the diet. Liener [22] indicated that the amino-acid lysine might be rendered totally unavailable by toasting. Lysine is already the limiting essential amino-acid in bread, and any reduction will further reduce the biological value of the bread proteins. In fact, according to the findings of Heupke and Kittelman [72] and of Block and Mitchell,[61] the biological value of toast is so low that it will not support the growth of a young rat.

Zaehringer and Personius [73] showed that the B vitamins present in bread were destroyed by strong heat; analysis of the crust and crumb portions of normal bread revealed the almost total absence of B vitamins from the crust. Heupke and Kittelman [72] and Goldberg and Thorpe [74] reported the destruction to be approximately 20% under normal good baking conditions. In toast the destruction is frequently complete.

On the other hand, the digestibility of bread is increased by toasting. Kestner and Warburg,[16] Haggard [75] and O'Rourke [8] recorded that, toast being easily chewed, salivary digestion was rapid and often as much as 80% complete. In many cases part of the carbohydrate will have been converted already into dextrin, thus facilitating rapid digestion. Kestner and Warburg [16] observed formation of a fine particulate chyme in the stomach and a fuller secretion of gastric juice produced by toast than by normal bread. Lehman and Gibson [18] noted that the smaller particles provided a greater surface for the activity of the digestive juices throughout the digestive tract.

Excessive heat, other than dry heat, does not appear to improve the digestibility of bread. Yenson [19] found that steam heat and hot frying retarded the digestion of the protein and served only to over-cook the starch.

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CHAPTER SEVEN

BREAD AND NUTRITION

THE NUTRIENTS IN BREAD

An adequate diet requires carbohydrates, proteins (essential amino-acids), fats, vitamins and mineral salts in suitable proportions. It must provide an energy value (calories) sufficient for requirements.

Calories

The following figures give the available energy content of flour and the corresponding bread.

			Calories per lb.
70%-extraction flour			1,553
85%	,,	,,	1,536
100%	,,	,,	1,413
70%	,,	bread	1,150
85%	,,	,,	1,121
100%	,,	,,	1,009

The energy content of fancy breads containing a proportion of added fat is slightly higher, since one part of fat has two and a quarter times the energy content of the same weight of protein or carbohydrate.

Vitamins

Vitamins are organic compounds present in minute quantities in food; their presence is essential to life and health. Several of them are known to form part of the complex enzyme systems which enable the cells of the body to utilise food.

The vitamin content of the wheat grain varies greatly from one part to another.* The vitamin content of unenriched flour thus varies according to the parts that it

* See pp. 45; 134.

includes. The extraction rate measures this only approximately; and two flours of the same percentage extraction may have widely differing vitamin contents.

Vitamin A promotes growth in the young and helps to maintain the health of body epithelia. A deficiency leads to an increased susceptibility to infection by organisms entering via the epithelia lining the alimentary and respiratory tracts.

Vitamin C (ascorbic acid) is important for maintaining the normal state of the intracellular cement substance. A deficiency leads to delayed wound healing; a gross deficiency gives rise to scurvy.

The absorption of vitamins A and C from diets containing only small amounts of foods other than bread became a critical problem in refugee camps and schools after the War. Balliette *et al.* (1950) [1] found that on white bread children in Naples developed vitamin-A and ascorbic acid deficiencies. The same result would have obtained with any type of bread, since the wheat grain contains insignificant amounts of these vitamins.

Vitamin B is not a single vitamin, but a series of water-soluble vitamins concerned among other things with the metabolism of carbohydrates in the body.

Vitamin B_1 (aneurin or thiamine) is particularly important for carbohydrate metabolism. The precise amount necessary is not known and depends on a number of factors, including the amount of fat in the diet. For a given calorie intake children and pregnant women require a greater amount of B_1 in the diet. As a rough guide, however, it may be assumed that 0·06 mgm. of vitamin B_1 is required to metabolise every 25 gm. of carbohydrate (or protein if protein is used to provide energy); i.e., the desirable ratio is 0·6 mgm. of B_1 to 1,000 non-fat Calories. Since the major part of bread is carbohydrate, the simultaneous intake of vitamin B_1 is of great importance. A deficiency leads to retarded growth in children, lack of appetite, apathy and disinclination for physical or mental work, leading to muscular weakness and nervous disturbances. A severe

deficiency results in the disease beri-beri. Harris [2] describes its symptoms as including:

(1) Polyneuritis (i.e., multiple symmetrical peripheral neuritis or " neuropathy ", of which the typical manifestations include patches of paraesthesia in the lower limbs, absent knee-jerks, wrist-drop, high-stepping gait, muscular weakness).

(2) Cardiac insufficiency (dyspnœa, tachycardia), with dilatation of the right side of the heart.

(3) Anorexia, and (sometimes) emaciation.

Beri-beri is unknown in the United Kingdom except as a medical curiosity; it is, however, encountered in rice-eating countries where polished rice deficient in B_1 constitutes the bulk of the diet.

Vitamin B_1 is present in wheat, and therefore in whole-wheat bread. Hinton (1947) [3] has shown that 62% of it is located in the scutellum of wheat germ and 30% in the aleurone layer; very little is to be found in the embryo fraction of the germ or in the endosperm. Thus the vitamin is largely eliminated in the milling of white flour.

The vitamin B_1 content of bread was studied in man by Bigwood *et al.* (1940) [4] and in the rat by Henry and Kon (1945).[5] In both cases the results obtained indicated that whole-wheat bread contained substantially more vitamin B_1 than white bread made from unenriched flour, but that the percentage absorbed decreased as the extraction rate of the flour rose. Stevens *et al.* (1952) [6] recorded that the fineness of the bread did not affect the absorption of the vitamin.

Other important vitamins of the B group are nicotinic acid (niacin) and riboflavin. A deficiency of nicotinic acid leads to infection of the mouth and tongue, dermatitis, diarrhœa and mental deterioration. The bran of the wheat grain is particularly rich in this vitamin: Heathcote *et al.* (1952) [7] have found 80% of the total to be present in the aleurone layer and only 12% in the endosperm; the scutellum and embryo are poor sources. A deficiency of riboflavin leads to lesions in the mouth and increased

vascularity of the cornea of the eye. The amount of the vitamins of the B group as a whole naturally present in bread increases with the extraction rate, but Hinton *et al.* (1953)[8] have found that riboflavin, being distributed in the wheat grain more uniformly than the other vitamins, does not vary with the extraction rate to the same extent as do the others.

The addition of vitamin B_1 to flour, proposed by the British milling industry in 1938, was put into effect early in the War. Some 30% of the flour of the country was enriched in this way before the war situation led to the adoption of 85%-extraction flour. In 1953, when white bread was reintroduced, its enrichment with B_1 and nicotinic acid was made compulsory.*

Vitamin D is necessary to prevent rickets. It may be obtained from the diet or formed by exposure of the skin to sunlight. The extent and ease of its absorption from bread are not clear, since its concentration is too low to be assayed in the presence of phytic acid, which acts as an antagonist in the calcium-vitamin D and phosphorus balance. In experiments in which vitamin D has been added as a supplement, in the form of cod-liver oil, etc., absorption of the vitamin does not seem to be impaired by white bread—although it must be remembered in this connection that white bread has a low phytic acid content.

Vitamin E, the fat-soluble tocopherol complex, is present in whole-wheat bread, and Engel[9] has found that even bread made from flours of low extraction contains appreciable amounts. Its presence is essential to the rat to prevent sterility, but its importance to man has not as yet been fully assessed.

Minerals

The mineral resources of bread are diverse,† but by no means large. However, such is the quantity of bread consumed that their contribution to the diet from this source is

* See below, p. 161. † See above, p. 57.

considerable. Their highest concentration in the wheat grain is in the bran and germ.*

The important question is the extent to which these minerals are available to man. Most of the potassium, magnesium and calcium, and possibly some of the iron, is combined with the organic phosphorus compound, phytic acid, which accounts for approximately 70% of the total phosphorus of wheat. The phosphorus, and in turn the phytate P content of wheat, is greatest in the germ and branny layers. Thus, whilst a representative figure for the phytate P of wheat is of the order of 250 mgm./100 gm., that for commercial bran cleaned in the laboratory (and essentially pericarp, seed-coat and aleurone layer) is 1,200 and for germ 570 mgm./100 gm.[10] The fact that the concentration of phytase is greatest in the aleurone layer is also consistent with the fact that this is the site of the bulk of the phytic acid.[11] During fermentation and baking much of the phytic acid is broken down into inositol and phosphoric acid, thereby releasing corresponding amounts of any bound calcium and magnesium. Phosphorus is also present in nucleoprotein, lipoids and in combination with starch. Part of the iron in wheat is in an ionisable form.

Little is known about the mode of combination of the trace elements; some of them are constituents of certain of the enzymes.

Phytic Acid as a Source of Phosphorus

Much of the phosphorus present in bread is in the form of phytic acid (phytin or inositol hexaphosphate). The percentage in this form varies from 15% in 70%-extraction bread to 55% in 90%-extraction bread, confirming that the greatest concentration of phytic acid is in the germ and bran layers.† The availability of the phosphorus in phytic acid for absorption, however, depends on the level of calcium present.

Bruce and Callow (1934) [12] held that the phosphorus of phytic acid was unavailable for absorption. Lowe and

* See above, p. 47.

† See above, p. 44.

Steenbock (1936)[13] found, however, that rats fed on no other sources of phosphorus than bread were able to digest a large proportion of the phytic acid present; this was reduced when calcium carbonate was added as a supplement to the bread.

McCance and Widdowson (1935)[14] observed that up to 60% of the phytic acid ingested in bread was excreted unchanged in man, but later (1942)[15] they estimated that for normal concentrations of phytic acid up to half the phosphorus present in the phytic acid was absorbed. Walker *et al.* (1948)[16] demonstrated that if the overall mineral (calcium and magnesium) concentration was low, the phosphorus absorbed from phytic acid was raised.

Schulerud (1947)[17] showed that the phytic acid was hydrolysed and broken down by the hydrochloric acid present in the stomach in the absence of calcium and iron ions. In the presence of such ions, insoluble salts are formed. It seems probable that magnesium ions can act in a similar fashion.

The conclusion reached by the Cereals Committee of Copenhagen in 1946[18] was that the absorption of inorganic phosphate does not appear to be much affected by changes in phytic acid content; and it is doubtful whether the increased phosphate uptake in the presence of high concentrations of phytic acid, as recorded by Höff-Jorgensen *et al.* (1946),[19] can really be claimed to be inorganic phosphate rather than an increase in the amount of phytic phosphate absorbed.

Phytic Acid and the Assimilation of Other Minerals

In addition to being a source of phosphorus for the body, the phytic acid content of bread modifies the absorption of calcium, magnesium and iron from the bread. As long ago as 1921 Mellanby[20] suspected that cereals impaired the metabolism of calcium and phosphorus, and thirteen years later Bruce and Callow[12] were among the first to find that phytic acid was responsible for interfering with calcium absorption from bread.

McCance and Widdowson in 1942,[15] in a study of several breads, established that not only was phytic acid capable of interfering with calcium absorption, but so were the products of its hydrolysis. The effect was very small in so-called " dephytinised " bread, but not completely absent even in white bread. They postulated that the products of hydrolysis might include phosphates capable of forming insoluble calcium salts.

Henry and Kon (1945),[5] who found that calcium supplements were more effective in raising calcium absorption when added to white bread than when added to whole-wheat bread, deduced that the phytic acid of whole-wheat bread interfered with the absorption of calcium.

In a further study, McCance and Walsham (1948) [21] found that six adult subjects, subsisting on a diet in which bread provided 85–100% of the calorie intake, were all in negative calcium balance over a period of eleven days and that one, in fact, on the fourth day had a severe attack of tetany. Widdowson and Thrussell (1951) [22] showed that a number of adult male Germans, existing mainly on bread made from high-extraction wheaten flour were all, with one exception, in negative balance over a period of fourteen days.

Nevertheless, it now seems likely that the effect of phytic acid on the absorption of calcium in man is less than was at first suspected. Walker *et al.* (1946) [23] indicated that in most cases the initial slight negative balance disappeared because the low dietary calcium level evoked a more efficient mechanism for the absorption of calcium. Balliette *et al.* (1950) [1] found that, in other cases, a very small addition of calcium salt sufficed to restore a positive calcium balance. The findings of Nicolaysen and Njaa (1951) [24] showed that the antagonism of phytic acid depended not only on the amount present but also on the amount of calcium present simultaneously in the stomach and intestines. Mellanby (1949) [25] has shown that calcium absorption is facilitated by vitamin D, even in the presence of the large amount of phytic acid to be found, on occasion, in whole-wheat bread. In all, there is much evidence to support the contention of

Walker (1951) [26] that the antagonism of phytin to the absorption of calcium is not highly significant.

The mechanism of the absorption of *magnesium* is probably similar to that of the absorption of calcium. McCance and Widdowson in 1942 [15] found that phytic acid had a detrimental effect on the absorption of magnesium. Lowering the concentration of phytic acid appears to improve the absorption of magnesium more than it does that of calcium. Widdowson and Thrussell (1951),[22] however, reported that, both in man and in the rat, the magnesium available in most commercial types of bread was sufficient to maintain a positive magnesium balance.

Baking and Phytic Acid

The phytic acid content of bread can be kept to a minimum by careful baking, and, indeed, bread of good quality, with a low phytic acid content, can be produced without the application of any specific measures to remove the phytic acid. Regulation of such factors as the pH of the dough, the duration of yeast fermentation and the conditions of baking were found by Lee and Underwood (1949) [27] to result in considerable destruction of the phytic acid, even in whole-wheat bread. Pringle and Moran [10] have shown that the lowering of the pH to 5·2 by means of lactic acid and allowing four hours for fermentation can eliminate up to 75% of the phytic acid. This destruction of phytic acid during fermentation is due to the activity of the enzyme phytase, acting on the phytic acid, which is enhanced by slightly acid media (pH 4·5–5·2).

The influence on phytic acid of other processes in baking is small. Baking-powder tends to inhibit the phytase reaction. Extra calcium salts slightly accelerate the enzyme activity, and were found by Mollgaard,[28] in some circumstances, to permit phytic acid hydrolysis on a larger scale than normal; but any advantage gained here is countered by the inability of the gastric juices to carry out extensive hydrolysis in the presence of calcium salts. In 1942 the British Government decided that calcium in the form of chalk (*creta praeparata* B.P.)

should be added to National flour (then 85%-extraction) at the rate of 7 oz. per sack of 280 lb. (155 mgm./100 gm.) in order to "neutralise" the phytic acid. The phytate P of commercial 85% flour is approximately 110 mgm./100 gm. About half of this is destroyed during baking, leaving a residue of approximately 55 mgm./100 gm. which would require at the most addition of 270 mgm. of *creta* to every 100 gm. of flour for its complete neutralisation.

The amount of *creta* added was later increased to 14 oz. per sack, and this is the quantity added both to National and to white flour. In the latter case, however, the purpose of the *creta* is not to counter any phytic acid present in the flour, which in fact is negligible, but solely to augment the intake of calcium per head of the population.

Iron

The majority of the iron of the wheat grain is found in the outer layers. Table 1 gives the iron concentration in different milling products.

TABLE 1 *

Milling product.	Iron concentration, mgm./100 gm.
White flour (unenriched) . .	1·4
Germ	5·8
Bran	14·1
Whole wheat	5·1

The amount of iron in unenriched flour will depend on the percentage extraction (Table 2) and to a small extent on the contamination from steel rollers during milling.†

A deficiency of iron in the diet leads to a deficiency of hæmoglobin in the blood, a condition known as iron-deficiency anæmia. Table 2 indicates that the iron content of whole-wheat bread is higher than that of white bread. However, the amount of iron absorbed depends firstly on the body's needs and secondly on the availability of the iron

* From Table 9, p. 49 above. † See above, p. 47.

TABLE 2 *

Extraction, %.	Iron concentration, mgm./100 gm.
100	3·1
85	2·2
80	1·7
70 (unenriched)	1·4

in the diet. Not all the additional iron in whole-wheat bread is available for absorption. Iron is readily absorbed in the form of simple salts such as iron sulphate, but is not readily absorbed from complex organic molecules. Whole-wheat bread is richer than white bread in certain proteins which form insoluble iron-protein complexes antagonistic to the absorption of iron from the intestines.

Whole-wheat bread contains phytic acid, and iron phytate is practically insoluble, as also is iron phosphate formed from the phosphoric acid released after the break-down of phytic acid.[29] Iron phytate and phosphate have been shown by many workers [30, 31, 32] to be less completely absorbed than iron sulphate in man. Others [33, 16, 34] have indicated that phytic acid itself has little effect on iron absorption when both are present as normal constituents of bread. The formation of iron phosphate, due to the presence of phosphate ions, appears to be of greater importance in making iron unavailable.

Small supplements of iron to National bread were not found by MacKay *et al.* (1945) [35] to increase the hæmoglobin analysis in children in English war-time nurseries. They are, however, desirable in white bread, and such supplements are in fact now added to white bread in the United Kingdom.†

Of the minor elements in bread only *lithium* need be mentioned. Kent and McCance (1941) [36] showed that it was poorly absorbed, especially from brown bread. The reason is unknown, but phytic acid is not likely to be responsible as lithium phytate is soluble.

* From Table 11, p. 53 above. † See below, p. 161.

THE NUTRITIONAL REQUIREMENTS OF MAN

The nutrients found in bread having been described, they can now be related to the nutritional requirements of man.

The report of the Technical Commission of the League of Nations (1938),[37] the Recommended Allowances of the Food and Nutrition Board of the National Research Council of the United States (1943, 1945 and 1948) [38] and the Report of the Committee on Nutrition set up by the British Medical Association (1950) [39] are the standard works on human nutritional requirements. The B.M.A. Report is taken as our reference not only because of its distinguished membership, but also because it is the most recent. Subject to certain special needs, the Report gives the following average nutritional requirements for good health and well-being:

Energy. For ordinary living, apart from any special form of activity, the basic daily requirements for adult males and females are 2,200 and 1,800 Calories respectively. The following additional Calories per hour are required for the stated type of activity: *

Type of activity.	Male.	Female.
Sedentary	30	30
Light effort	70	70
Moderate effort	100	100
Heavy effort	200	200
Very heavy effort	300	300
Exceptionally heavy effort	450	—

Protein cannot yet be assessed. As a guide the Committee recommends that in a mixed diet 14% of the Calories in the form of protein should be sufficient for pregnant and nursing women, infants, children and adolescents. For adults not engaged in hard work, protein should provide 11% of the Calorie intake.

Calcium and Iron. The Committee accepted the standards laid down by the N.R.C. (1945), ranging in the case of calcium from 0·8 gm. for an adult to 1 gm. for a child, with larger amounts for the special categories of adolescents (1·3–1·49), pregnant women (1·5) and nursing mothers (2 gm.). The corresponding range for iron was from 12

* See also below, p. 174.

for adults to 6·59 mgm. for children, with 13·5–15·9, 15·9 and 15·9 mgm. for the other three categories.

Vitamin A. 2,500 i.u. vitamin A, or 7,500 i.u. carotene, for adults and adolescents.

Vitamin B_1. For all except nursing mothers:

0·4 mgm. per 1,000 total Calories.
0·6 mgm. per 1,000 non-fat Calories.

Riboflavin. 0·6 mgm. per 1,000 Calories.

Nicotinic Acid. 4 mgm. per 1,000 Calories.

Other B Vitamins. It is not yet possible to assess human needs for folic acid, pyridoxin, pantothenic acid and biotin.

Vitamin C. 30 mgm. daily for adults.

Vitamin D. Allowances are specified for children and pregnant and nursing women, but it is not yet possible to indicate the amounts required by normal adults.

The Report gives finally the daily requirements per head of the United Kingdom's population in 1948 and also the corresponding figures based on the recommendations of the National Research Council.

	Per head daily requirement.	
	B.M.A.	N.R.C.
Calories	2,554	2,564
Protein (gm.)	71	65
Calcium (mgm.)	917	917
Iron (mgm.)	11·8	11·8
Vitamin A (i.u., mixed diet *)	4,570	4,460
Vitamin B_1 (mgm.)	1·02	1·27
Riboflavin (mgm.)	1·53	1·74
Nicotinic acid (mgm.)	10·2	12·7
Vitamin C (mgm.)	20–30	71
Vitamin D (i.u.)	150	130

* 1/3 vitamin A, 2/3 carotene.

Of these ten nutritional factors, bread is important in respect of seven. Thus 1 lb. of bread made from 80%-extraction flour contains the following:

Calories	1,140
Protein	40 gm.
Calcium	480 mgm.
Iron	6·5 ,,
B_1	0·6 ,,
Riboflavin	0·3 ,,
Nicotinic acid	4·8 ,,

In the baking of bread approximately 4 lb. out of each 280 lb. of flour is broken down into carbon dioxide and other volatile bodies.

Ordinary bakers' yeast contains 75% water, so that each 100 gm. of the yeast contains the following nutrients:

Protein	12 gm.
Fat	0·5 ,,
Calcium	10·5 mgm.
Iron	6·5 ,,
B_1	0·8 ,,
Riboflavin	1·85 ,,
Nicotinic acid	9 ,,

Thus the yeast used in bread-making—on average, less than 1% by weight of the bread—cannot be said to contribute significantly to the nutrient content of bread.

EXTRACTION RATE AND THE NUTRITIVE VALUE OF BREAD

In bread-making broadly four types of flour are involved: (i) brown flour of 90–100% extraction; (ii) flour of 80–85% extraction, the National flour introduced into the United Kingdom during the Second World War; (iii) white flour of about 70% extraction, in general use before the War; and (iv) white flour of 70% extraction enriched with certain nutrients, introduced into the United Kingdom in August 1953.

The wheat grain and flours of different extraction have been analysed in considerable detail above,* and it is worth considering the conclusions that can be drawn from those data. In the first place, in practice, as the extraction of flour falls, there is a progressive decrease in the content of its vitamins, minerals and phytic acid. The decrease is not linear because, as has been seen,† the B_1 (for example) is located mainly in the scutellum fraction of the wheat germ. In orthodox milling the germ tends to be present in the bran-rich streams, and much of it finds its way into wheat-feed. Unless the bran is carefully scratched or cleaned it takes

* See above, Ch. 3. † See above, p. 134.

with it most of the aleurone layer and any attached endosperm, both of which are rich in nutrients. In the war years, in milling 85%-extraction flour, the millers by suitable modifications to their operations * were able to trap most of the germ and include it in the flour. The bran was well cleaned to detach its adhering endosperm and part of the aleurone layer. As a result, a flour was ultimately produced which contained the following amounts of the four more important nutrients:

B_1	0·28 mgm./100 gm.
Riboflavin	0·13 ,,
Nicotinic acid	1·70 ,,
Iron	2·07 ,,

Indeed, Moran and Drummond [40] have shown that, theoretically, it is possible to mill a flour of 80% extraction which has a higher proportion of B_1 than that of its parent wheat. Such perfection, however, has not been achieved yet in commercial milling.

In addition to the fall in vitamin and mineral content, there is a decrease in protein content when the extraction rate is reduced. Thus the protein content of a 70%-extraction flour is 7·92%, compared with 8·89% for the whole wheat from which it is milled.†

It has been observed ‡ that the proteins of low-extraction flour have a different construction of amino-acids, with a lower biological value, from those of whole wheat; the reduction is unimportant unless bread forms the bulk of the diet, for the amino-acid deficiencies are made good by the other proteins in the diet. In fact, Staudt in 1947 [41] showed that a mixed diet removed the difference in nutritive value between breads made from 70%- and 100%-extraction flour. High-extraction flours, however, inevitably contain a large proportion of bran, and as a result suffer from two defects (i) a lowered digestibility, and (ii) a high content of phytic acid.

The Medical Research Council, during the Second World

* See above, p. 75.
† See above, p. 53.
‡ See above, p. 121.

War, advised that the extraction rate of National flour should be 85%. Apart from the fact that such flour gave a loaf generally preferable to wholemeal * bread, it was in the interests of the national economy that the 15% fibrous bran or offal, of low digestibility in man, should be fed to animals who could utilise it better and give a return in animal protein. The specifications for National flour issued by the Medical Research Council in 1941 [42] contained the following:

"Special Nutritive Properties of the Selected Flour.

"The degree of extraction was fixed at 85% in order to secure a flour which should contain:

(1) As much as possible of the B vitamins, including riboflavin and nicotinic acid, and especially of the vitamin B_1 present in the whole wheat.

(2) As much protein as possible, including a high proportion of that situated in the outer layers of the grain. This protein is known to possess a higher nutritive value than that contained in white flour.

(3) As little bran as possible so that there should be no risk of loss of nutritive value due to presence of much indigestible material. War-time diets already contain much vegetable food with relatively large amounts of roughage; it is undesirable to increase this further.

"Wholemeal bread and bread made from flour of 85% extraction contain more calcium than white bread and also more phosphorus. A large proportion of the phosphorus, however, is present in a combination (phytic acid) in which it is not directly available to the organism and at the same time diminishes the availability of the calcium present in the bread and in the rest of the diet."

The Conference on the Post-War Loaf (1945) [43] recommended that a National flour should contain the following minimum quantities of three token nutrients, viz.:

B_1	0·24 mgm./100 gm.
Nicotinic acid	1·60 ,,
Iron	1·65 ,,

* i.e., 100%-extraction.

The extraction of National flour was reduced to 80% on January 1st, 1945, following research on the distribution of the vitamins in wheat and improvements in milling technique. Extensive analyses of this flour showed that the levels of nutrients were maintained.

If, on general nutritional grounds, an 80–85%-extraction flour would appear to be preferable to one of higher extraction (including wholemeal), the problem of unenriched white (*circa* 70%-extraction) versus an 80–85%-extraction flour is more difficult. The phytic acid and digestibility aspects do not enter, and the comparison rests on differences in the biological values of the proteins and the content of vitamins and minerals. On both scores the 80–85%-extraction flour is superior.* However, as bread is only part of our diet, the supplementary action of the other proteins in the diet is likely to smooth out the differences in the nutritive values of the protein of the two flours. Furthermore, the rest of the diet must also make its contribution of vitamins and minerals: it must, for example, supply the whole of the vitamins A, C and D which are virtually absent from flour. Surveys carried out by the Ministry of Food have shown this to be the case. Table 3 shows how far the B.M.A. standards were reached in different households in the survey carried out by the Ministry of Food in 1950.[44]

It is clear that in respect of most of the nutrients there is a generous margin of safety even if the B.M.A. standards are rigidly accepted. It is only in those households with four or more children that some of the nutrient levels are marginal.

Another argument advanced against unenriched white flour is that the " balance of its nutrients " is different from that in 80–85%-extraction flour. It is difficult to recognise precision in this argument. The wholemeal school might well advance the same argument against 80–85% flour if indeed the argument is to be taken literally.†

* It should be remembered that the vitamin B_1, nicotinic acid and iron content of the enriched white flour sold in the U.K. is equal to that of an 80% flour. (See below, pp. 161, 171.)

† See above, p. 54.

TABLE 3

Comparison of Energy Value and Nutrient Content of Domestic Food Consumption with Standards based on the British Medical Association's Recommendations 1950

	Households with one male and one female adult and						
	No children.	Children.				Adolescents.	Adolescents and children.
		1.	2.	3.	4 or more.		
	%	%	%	%	%	%	%
Energy value .	106	109	103	104	101	100	96
Total protein .	123	117	105	102	94	103	91
Calcium .	136	120	106	102	92	114	94
Iron . .	121	123	114	111	107	115	107
Vitamin A .	145	179	175	163	165	149	144
Vitamin B_1 .	139	143	137	137	134	132	125
Riboflavin .	135	126	121	117	109	110	101
Nicotinic acid.	146	146	136	130	123	136	124
Vitamin C .	271	266	240	216	174	226	189

The work of Richards [45] (1949) is sometimes quoted in this connection and also as an argument against the enrichment of white flour. She found that when a large excess of vitamin B_1 is added to an otherwise adequate diet the growth and reproduction of rats were satisfactory, but that during lactation young rats had convulsive fits characteristic of pyridoxin deficiency; the fits could in fact be prevented by adding a supplement of pyridoxin to the diet. These experiments, however, can have little relation to the question either of the " balance " of the naturally occurring vitamins in flour or to their " balance " in enriched flour, since the supplement of vitamin B_1 was so very high. It averaged 8·5 mgm./100 gm. of flour, whereas the total content of B_1 in 80%-extraction flour or enriched white flour * is 0·24 mgm./100 gm.

It might also be pointed out that all nutritional standards with the exception of those related to energy cannot be precise, since individuals inevitably differ in their require-

* See below, p. 161.

ments. Moreover, standards are based largely on experience of what is required for good health. It is likely therefore, and in fact desirable, that they should be in excess of minimum levels.

Recent work by McCance and Widdowson, of which only short abstracts have been published,[46] should help to resolve the white versus high-extraction flour controversy. In 1945 the Post-War Loaf Conference [43] was called by the Ministry of Food to decide on the nature of the post-war National flour. The Conference was composed of representatives of all the interested Government departments and of the milling and baking industries. The official members favoured a continuance of an 80–85%-extraction flour, whereas the trade interests, having in mind the preference of the bulk of the nation, favoured a white flour enriched if necessary with the nutrients normally present in wheat, after the practice of many other countries, including the U.S.A. No compromise was reached, but the trade representatives asked that an investigation should be made to compare the merits of the two types of flour. This investigation was conducted by McCance, assisted by a team of medical and scientific experts, on two large groups of German school children. The diets were chosen deliberately to magnify any differences between the flours but in fact the results showed no difference. The children, originally underweight and under-nourished, gained weight rapidly, and soon caught up in weight and height to the levels of the best-fed American children; their health was excellent. Five flours were tested: wholemeal, 85%-extraction flour, 70%-extraction flour, 70%-extraction flour enriched with B_1, riboflavin, nicotinic acid and iron to 85% levels, and 70%-extraction flour similarly enriched to wholemeal levels. The children throve equally well on all the flours.

Nevertheless, whilst this investigation should put the problem of the nutritive value of flour in its proper perspective, it cannot be the last word. A national nutritional policy must be elastic in the sense that it should take into account changes in dietary habits due to shortages or

economic factors. For example, a reduction in the consumption of fruit with its content of vitamin C calls for a compensatory increase in the consumption of green vegetables and/or potatoes. Margarine is enriched with vitamins A and D because we do not eat much butter. It must also take into account developments in nutritional science, which is still young and to a large extent empirical. A case in point is the requirement of vitamin C. For normal adults the National Research Council (U.S.A.) has fixed the requirement at 70–75 mgm. per day. The B.M.A. Committee, basing its recommendation on experience in this country during the War, considers that 30 mgm. daily will provide a good margin of safety. Again, in the case of wheat, as with all foodstuffs, a host of substances present in trace amounts await identification; and, once identified, their importance in nutrition has to be assessed. As an example, two substances, mono- and dimethoxy-*p*-benzoquinone, have been isolated from fermented wheat-germ by Cosgrove *et al.* (1952); [47] they are probably present naturally in combination with a sugar. What is the function of these two curious substances and of others which in due course may be recognised?

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CHAPTER EIGHT

THE ENRICHMENT OF FLOUR AND BREAD

As bread is the food of the people, it is not surprising that many attempts have been made to make it more nutritious or to "enrich" it. Fat, when available, has long been incorporated in bread, primarily to improve its palatability, but, in the present century at least, the effect on its nutritive value has been insignificant; the fat is usually a hydrogenated product, and the amount added has been too small even to increase its calorific value to any appreciable extent. A customary addition to flour for bread-making is 2 lb. of fat per sack of 280 lb., which increases the calorie value per unit weight of flour (or bread) by 1%. For certain fancy breads, however, such as Bridge rolls, the addition may be as high as 6 lb., in which case the calorie value per unit weight of bread is increased by 3·5%.

Soya Flour is often suggested as a desirable ingredient of bread; indeed, it has been claimed that bread could carry 10–20% of a good full-fat debittered soya flour.[1] The flour is of two types: normal full-fat and the defatted variety or soya grits. McCance and Widdowson [2] give the following analyses:

	Protein.	Fat.	Available carbohydrate.
	Gm. per oz.		
Soya full-fat flour . . .	11·5	6·7	3·8
Soya low-fat flour or grits .	14·1	2·0	4·9

The grits, because of their lower fat content, have a correspondingly higher content of mineral salts and vitamins. Bread, however, will carry a higher percentage of the full-fat flour. Even so, our experience is that the maximum amount of either flour which can be incorporated in bread is about 2%. Above this figure the quality of the loaf suffers, and at about 4% the bread acquires a bean-like taste.[3]

There is a case on nutritional grounds for adding soya

flour because its protein is superior to that of wheat in respect of lysine—in which wheaten flour is relatively deficient (cf. Table 1).[4]

TABLE 1

Calculated to 16·0 gm. of Nitrogen

Amino-acid.	% of Amino-acid in the proteins of			
	Wheat.*	Soya bean.	Cows' milk.	Yeast.
Lysine	2·7	5·8	7·5	6·0
Phenylalanine	5·7	5·7	5·7	4·1
Tryptophane	1·2	1·2	1·6	1·8
Methionine	2·5	2·0	3·4	2·0
Threonine	3·3	4·0	4·5	5·0
Leucine	6·8	6·6	11·3	7·3
*iso*Leucine	3·6	4·7	8·5	6·0
Valine	4·5	4·2	8·4	5·3

* A slight difference will be noted between these values and those given for whole wheat in Table 3 on p. 117, above, which were obtained by a microbiological technique. These are considered the best available for the *relative* amino-acid composition of the different food proteins, and are therefore particularly suitable for the present discussion.

Experiments, largely on the growth rate of rats, have confirmed the beneficial effects of an addition of soya flour, a 3% soya-flour white bread, for example, being the equal of a 3% skimmed-milk bread.[5]

Soya flour is also notable for the fact that the nutritive value of its protein is increased by a mild heat treatment. Its digestibility is improved probably as the result of the destruction of a factor inhibiting proteolysis; so, too, is its biological value,* owing, it is believed, to an increase in the availability of its contained cystine.[6] The beneficial effect of heat is also connected with the destruction of a protein fraction, " soyin ", which is toxic to rats.[7, 8]

Milk Powder. Probably the most important addition to, or form of enrichment of, bread is by skimmed-milk powder. This is commonplace in the U.S.A. and Canada, where the percentage of milk solids in bread-making flour is in the range 4–6%. It is unusual in this country because cheap supplies of milk powder are not available.

* See above, p. 119.

Addition of the ordinary skimmed-milk powder lowers the quality of bread, and 6% gives a very poor loaf.[9] This effect has been related to the action of the milk proteins (lactalbumin and lactoglobulin), and can be overcome by a specific heat treatment of the milk before it is dried. The treatment is 73° C. for thirty minutes, 85° C. for seven minutes, or 92° C. for one minute. It was suggested that this heating involves a molecular rearrangement of the proteins by which some of the –SH groups are rendered unavailable or inactive,[10] but more recent work has not supported this theory.[11] In addition extra fat added at dough-making helps to maintain the baking quality of the loaf.[9]

Many investigations have shown the superior nutritive value of milk-enriched bread over ordinary bread when it provides the exclusive diet of the experimental animal, usually the rat. Kon and his colleagues [12] concluded that this superiority rested largely in its content of calcium, riboflavin and other members of the B complex and in the higher quantity and quality of its protein. Other workers, including Light and Frey,[13] claim that the difference is due in part to the higher calcium content of milk bread, but principally to the enriching effects of the lysine and valine in the milk protein. They found that white bread containing a supplement of lysine and valine together with mineral salts and vitamins gave better growth than 6%-milk bread. Sure [14] would go further and attach importance to the higher content of threonine in milk protein. On the other hand, Rosenberg and Rohdenburg [15] assert that the vitamin supplement should contain B_{12}, in which case lysine only would be the key amino-acid.

Milk is rich in riboflavin, in which flour and bread are relatively deficient, and it is a particularly good source of calcium. Thus the addition of 6% of skimmed-milk solids to flour raises its calcium content by 82 mgm./100 gm.—equivalent to the increase produced by 9 oz. of *creta praeparata* per sack of flour.

Dried whey has also been suggested as an addition to flour and bread.[12] Its protein is, in fact, richer in lysine than is

casein. Relatively little work seems to have been carried out on the technical problems involved, but Fisher [16] reported that even with 5% dried whey the dough was sticky. It would therefore be difficult to handle in a large bakery. At an addition of about 5%, the loaf also tends to have a cheesy flavour.[12]

Food Yeast (Torula utilis). This is another possible addition to flour which has the support of many nutrition authorities. Its composition is sensibly the same as that of bakers' yeast (*Saccharomyces cerevivae*); it contains first-class protein, is rich in lysine * and is also an excellent source of the B group of vitamins. It is now grown in Jamaica on a commercial scale, using the waste materials from the sugar industry. A report by the Medical Research Council [17] describes the results of experiments on rats and young pigs, and concludes:

> "The results of the above experiments with animals show that the addition of food yeast greatly improves the nutritive value of a diet whose protein is otherwise derived mainly from cereals, the biological value of the mixture of the cereal proteins with those of yeast being equal to that of a similar mixture with those of milk. The good effects of the addition of food yeast to a white flour diet have demonstrated its value as a source of B vitamins."

Unfortunately, there is a limit to the amount that can be eaten without risk of digestive disturbance, which is of the order of ¼ oz. daily. 2% can be added to bread without any marked effect on taste; above this level the bread has a salty, yeasty flavour, although critical experiments by the Research Association of British Flour-Millers, with an experienced tasting panel, suggested a lower limit, viz. 1%. The Report states that "even with this small amount, i.e., 2%, the nutritive value of the bread, as regards its content both of protein and B vitamins, would be significantly enhanced".

In 1946 Platt [18] advised the addition of 2–3% food yeast to 80%-extraction flour together with a supplement of bone

* See Table 1, p. 153, above.

meal for use in the British West Indies, where much of the widespread malnutrition could be related to vitamin-B deficiency. Platt preferred to call this flour " ennobled wheat flour ", reserving the adjective " enriched " for flour containing added synthetic vitamins. His attitude to the general problem of enrichment is summed up in paragraph 28 of the Report, which reads:

> " The method adopted in the United States for introducing specific nutrients into flour, viz. enrichment with individual factors, is not recommended. The chief reason for preferring lengthening the extraction rate together with ennoblement to enrichment is that there is good reason to think that where measurable factors of the vitamin B_2 complex are deficient, other factors which are not yet measurable—and some which still remain unknown—will be deficient too. Since some at least of these are known to be important for health, a policy of enriching a low extraction (i.e., white) flour with two only of the B_2 group of vitamins must be regarded as unsatisfactory. Food yeast supplies the whole complex, and in addition the value of even a small amount of yeast protein in supplementing other proteins, especially cereal proteins, should not be overlooked."

We understand that, owing to certain technical difficulties, Platt's recommendation was never implemented in the West Indies.

High B_1 Bakers' Yeast. The vitamin-B_1 content of ordinary bakers' yeast is approximately 8 μgm./gm. Shortly before the War, however, a bakers' yeast was developed which had an unusually high B_1 content. This was achieved by growing the yeast in a medium containing the two penultimate fractions in the normal chemical synthesis of vitamin B_1; the yeast not only completed the synthesis but also absorbed the vitamin into its own framework. As a result, the B_1 content of this yeast averaged 300 μgm./gm.,[19, 20] and if used at the rate of $2\frac{1}{2}$ lb. per sack of 280 lb. of bread-making flour would raise the B_1 content of white flour from (say)

0·6 μgm./gm. to 3·3 μgm./gm., or somewhat above that naturally present in 85%-extraction flour. This clearly provided a method of enriching white flour with vitamin B_1; it was not, however, adopted in this country, mainly because the amount of yeast used by bakers varies widely from $\frac{1}{2}$ lb. to 5 lb. per sack, and it would be difficult to prescribe a fixed amount, such as $2\frac{1}{2}$ lb. per sack.

Fish Meal. Trials with bread supplemented with refined fish meal are at present (1954) being carried out in several areas of the world. Two of these trials are being conducted, in South Africa by the Dominion Government's Fisheries Research Institute, and in Chile by the UNICEF organisation of the United Nations.[21, 22] Thus far neither has published any results. In both cases the method has been to take highly refined fish meal, usually called fish flour, which has a high protein (75–90%) and calcium (5–20%) content, but a very low water (5–20%) and fat (2% or less) content, depending on the method of manufacture and the type of fish used. This fish flour is incorporated at 3–6% concentration in the dough. When the highest-grade fish flour is used no perceptible taste can be detected even at 6% levels in the bread, but with the poorer grades of fish flour the small extra amounts of fat and purines impart a characteristic taste to the bread. This taste, although objectionable to some at first, usually becomes acceptable after a few days. The gain in biological value is high, but as yet no figures are available.

Lysine. From what had been said about soya flour, milk powder and yeast, it was inevitable that consideration would be given to the possibility of enriching flour with pure L-lysine—the form in which lysine occurs normally. Flour, as we have seen, is relatively deficient in lysine and during bread-making there is a further loss, mostly in the crust, amounting to 15–30%.[23] Rosenberg and Rohdenburg[15] fed weanling rats on a basal bread diet (containing 90% of white bread), to which were added various amounts of lysine, and determined their gains in weight. Some of the results are given in Table 2.

TABLE 2

Five Weeks' Rat Growth on Bread Diets; Response to Increasing Amounts of Lysine

L-lysine added in diet, %.	Total L-lysine present in diet, %.	Total protein in diet (N × 6·25), %.	Average weight gain, gm.	Average % gain over starting weight.	Food efficiency.*	Protein efficiency ratio.†
0	0·29	12·50	58	121	0·13	1·06
0·1	0·39	12·75	102	210	0·19	1·56
0·2	0·48	13·00	135	277	0·24	1·89
0·4	0·67	13·50	180	377	0·28	2·12
0·8	0·99	14·50	180	366	0·27	1·90
Stock laboratory diet . .	1·10	21·50	151	312	0·28	1·31

* Food efficiency = gm. gain/gm. food consumed.
† Protein efficiency ratio = gm. gain/gm. protein consumed.

In these tests, 1·4 μgm. B_{12} was added to each 100 gm. of diet.

The final column of Table 2 provides much of the case of the advocates of lysine enrichment of flour. Thus Flodin [24] strongly recommends the addition of amino-acid supplements to the diet, by which, he claims, the effective supply of dietary protein can be increased by 50–100%; for diets in which wheaten bread is a staple food he suggests fortification with lysine alone. It is also interesting to read the views of Dr. Norman Jolliffe, the Director of the Bureau of Nutrition in the Department of Health in New York and a leading figure in the Enrichment Programme of the U.S.A.: [25]

> "Now by adding 0·2% of lysine to bread you can increase the availability of the protein for growth from 70 to 100%—a considerable increase in the biological value of that protein. All of this would represent a lot of meat that would stay in this country in the event of another war.
>
> "You would also increase the health standards and the national productivity by adding these amounts. I think

that it is up to the American people to develop some of these methods and to get them going in spite of the fact that the need in this country is small as compared with the needs of those overseas in the world today.

"There is considerable evidence, as you know, that cereal grains are very low in vitamin B_{12}. There is also some evidence that processing may destroy B_{12}. Therefore, our consumption of B_{12} is not as high as it is thought to be.

"The addition of B_{12} to cereal products, and even bread, is something that will be discussed in this country in the next 2 or 3 years. You may be putting it into some of your products in 4 or 5 years."

Recent reports in American trade journals state that a satisfactory synthesis of lysine has now been developed. This probably brings nearer enrichment with lysine.

Enrichment with Vitamins and Minerals

By far the most extensive form of enrichment has been the addition to white flour of certain of the B vitamins and iron. This has been in operation in the U.S.A. since May 1941, although it was pioneered in this country in 1940. Today, Great Britain, the U.S.A., Canada, Sweden, Australia, Chile and Brazil are among the countries in which enrichment in this form is carried out. It has been stated that roughly 250 million people are eating enriched flour in some form or other. Such a step, so revolutionary in its magnitude and implications, calls for an outline of its history and practice.

Great Britain. Before the last War, although the majority of the nation (estimated at not less than 95%) preferred white to brown bread, there was persistent criticism from many medical and scientific authorities that it was deficient in the B vitamins, notably vitamin B_1. As we now know, this was inevitable in the milling of a white flour, since the bulk of the B_1, being located in the scutellum fraction of the germ, tends to separate with the smaller bran fragments

rather than with the endosperm, and, if whiteness is the main object, is automatically diverted to wheat-feed. In the late thirties, however, one of us (E.C.D.) suggested to the British milling industry that it should consider the possibilities of enriching its white flour with synthetic vitamin B_1 at the rate of about 0·2 gm. per 280 lb. of flour. This step would raise the B_1 content of the flour by 1·5 μgm./gm. The suggestion then bordered on the fanciful because synthetic B_1 was only beginning to be produced commercially, and on the scale of production in 1938 was selling at 28*s*. 6*d*. per gram for bulk quantities (we understand that the first commercial production had sold at about £60 per gram). However, one of the large vitamin manufacturers undertook to produce it, on the vast scale that would be required, at 4*s*. per gram. This made the enrichment a practical proposition. The milling industry proceeded with its plans and through its Research Association worked out a novel method of adding the small amount of vitamin to the flour. This consisted essentially of preparing a batter of flour and vitamin B_1 which was then spray-dried. The resulting powder, containing 0·2 gm. of B_1 in each ounce, " flowed " easily, and machines were available to millers which would feed accurately and uniformly 1 oz. of this B_1 concentrate into each 280 lb. of flour. The outbreak of the Second World War disorganised these plans, but on July 18th, 1940, the Parliamentary Secretary to the Ministry of Food, on behalf of the Government, announced the adoption of the policy to enrich the then 73%-extraction flour with vitamin B_1 and also with a calcium salt.[26] This latter addition was delayed pending a decision as to the type and the amount of the salt,* but the milling industry, again through its Research Association, arranged for the use of a large milk-drying plant for the preparation of the spray-dried concentrate. By March 1942 about 38% of the flour of the country was being enriched, but in that month, owing to heavy shipping losses, the extraction of

* *Creta praeparata* as described in the British Pharmacopœia was ultimately chosen.

all flour was raised to 85%, and B_1 enrichment was no longer necessary. It is, however, of interest to note that the B_1 content of 73%-extraction flour averaged 0·90 μgm./gm., so that the enrichment process raised its B_1 content to something over 2·40 μgm./gm. or 0·80 i.u./gm., the level prescribed some years later by the Conference on the Post-War Loaf.[27]

On August 29th, 1953, millers were again allowed to mill white flour, but on condition that it was enriched, not only with vitamin B_1, but also with two other nutrients, viz., nicotinic acid and iron.[28] The minimum levels of these three factors in the enriched flour were set at those agreed as nutritionally desirable by the Post-War Loaf Conference, viz.:

B_1	0·24	mgm. per	100 gm. of flour	or 0.80 i.u./gm.
Nicotinic acid	1·60	,,	,,	,,
Iron	1·65	,,	,,	,,

This again required the preparation of a concentrate or "master mix", the composition of which was fixed by the milling industry in consultation with the Ministry of Food and the other departments concerned. For the time being at least, this is made simply by mixing intimately flour (of 10% moisture content) and the appropriate amounts of the three ingredients. Its composition is:

	Gm. per oz.
Vitamin B_1	0·21
Nicotinic acid	1·00
Iron (*Ferrum redactum*)	0·89
Dry flour	26·25

One ounce of this master mix is added to each 280 lb. of 70–72%-extraction flour and $1\frac{1}{10}$ oz. to each 280 lb. of a patent flour. With these additions the nutrient levels laid down by the Post-War Loaf Conference are achieved.

It is interesting to note that whereas the price of 4*s*. per gram of B_1 was a remarkable achievement in 1939, yet now, despite the rise in costs, vitamin B_1 for the enrichment of flour is being sold at about 11*d*. per gram. This is certainly a pointer to future prices, should other forms of enrichment

be contemplated, e.g., with lysine, B_{12} or other members of the B complex.

Side by side with this enriched white flour a National flour of, or equivalent * to, 80% extraction, but without enrichment, is also milled. This is in deference to that body of opinion (cf. Platt above) which prefers the desirable level of vitamins and minerals to be reached by "natural" means.

United States.† The enrichment of flour and bread in the United States was begun in May 1941. Undoubtedly one factor which stimulated this decision was the action of the British Government in the previous year in fortifying their white flour and bread with vitamin B_1.‡ [29] The enrichment programme initially was voluntary, the Federal laws insisting only that if flour was labelled "enriched" it must conform to the standards laid down. Nevertheless, by the beginning of 1951, twenty-six States and the territories of Hawaii, Alaska and Puerto Rico had passed laws for compulsory enrichment.

According to our information, 32% of the flour milled in the United States is family flour, i.e., flour sold through the retail trade direct to the consumer, and 68% is sold to bakers. About 99% of the family flour is enriched. The commercial bakeries do not generally use enriched flour in making rolls and sweet goods, but it is estimated that about 99% of the total bread is enriched. The enrichment levels at present in force are: [30]

	Flour standard.		Bread standard.	
	Min.	Max.	Min.	Max.
Mandatory :				
B_1 (mgm./lb.)	2·0	2·5	1·1	1·8
Riboflavin (mgm./lb.)	1·2	1·5	0·7	1·6
Nicotinic acid (mgm./lb.)	16·0	20·0	10·0	15·0
Iron (mgm./lb.)	13·0	16·5	8·0	12·5
Optional :				
Calcium (mgm./lb.)	500	625	300	800
Vitamin D (U.S. P. units)	250	1000	150	750

* See above, p. 51.

† For information on the more recent events we are greatly indebted to Professor W. F. Geddes of the University of Minnesota.

‡ See above, p. 160.

The Federal Standards also permit the optional addition of up to 5% of wheat germ (normal or defatted). It is understood that, in practice, none of the optional ingredients is added to flour.

As much of the flour milled in the United States is a patent flour, it is of interest to compare the levels of enrichment of this flour with those observed in this country.

Enrichment in mgm. per 100 gm. of flour.

Addition.	Great Britain.	United States. Min.	United States. Max.	Approx. enrichment necessary to bring to whole-wheat levels.
B_1	0·19	0·44	0·55	0·3
Riboflavin	—	0·26	0·32	0·1
Nicotinic acid	0·90	3·56	4·45	4·7
Iron	0·89	2·89	3·69	2·9

The degree of enrichment in the United States is therefore about three times that enforced in this country. Roughly speaking, the minimum standards correspond to the levels in the whole wheat.

In the United States all the family flour is enriched by the miller, but most of the bread is enriched by the bakers by means of enrichment tablets or wafers which are made and sold by various firms, including the leading vitamin manufacturers. The bakers enrich for two reasons: (i) they claim that their method is cheaper; (ii) they can buy wafers which contain a smaller equivalent amount of riboflavin—and which are therefore cheaper—if their bread-making formula includes a proportion of skimmed-milk powder.

Some of the larger bakeries also add vitamin D—one of the optional ingredients—to their bread. This step, however, is not popular among many of the nutritionists because calcium also is not added. Their view is that any enrichment with vitamin D should be confined to milk, which, incidentally, is a more important item in the diet of infants and young children than bread.[31]

Because of the large number of bakeries and the fact that enrichment is so much in the hands of the baker, the supervision of the enrichment programme is not easy. The

authorities would prefer to see it carried out by the miller, because the number of mills is relatively small and because it is easier to analyse flour than bread. In view, however, of the price differential mentioned above, it would be difficult to persuade the baker to buy enriched flour.

Canada. The enrichment of white bread was introduced on 1st January, 1953. The following standards were adopted : the bread must be made only of enriched flour containing 2% of skimmed-milk solids and certain nutrients in the proportions shown below :

	Mgm. per lb.	
	Min.	Max.
B_1	1·1	2·4
Riboflavin	0·8	1·8
Nicotinic acid	10	15
Iron	8	12·5

These are practically identical with the American standards.

The enrichment, although not compulsory, is widely carried out.

The Arguments For and Against Enrichment

Briefly, the argument against enrichment is that

(i) Enrichment implies a lower-extraction flour, and therefore the loss of a certain amount of the better-quality protein of the wheat grain and a lower level of certain vitamins and minerals;

(ii) Enrichment only restores a limited number of these nutritional factors, and cannot deal with nutritional factors which have not yet been identified.

The counter-argument is that

(i) The slightly lower biological value of the protein of enriched flour, compared with that of high-extraction flour, is more than compensated by the supplementary action of other protein in the diet;

(ii) Enrichment covers only those factors which have

been established as essential for health and of which there is a deficiency in the diet as a whole. Thus, in this country (unlike the U.S.A. and Canada), white flour is not enriched with riboflavin because surveys have revealed that the intake of this vitamin is already adequate.

Apart from any comparison with high-extraction flour

(*a*) Enrichment provides a method of making good any dietary deficiency, particularly of those nutrients for which a food is normally considered to be a good source. The addition of vitamins A and D to margarine is an excellent precedent. The addition of chalk to flour maintains our average calcium intake at its desirable level.*

(*b*) Many experiments on animals have shown that enriched flour ensures better growth than unenriched flour.[32]

(*c*) Surveys of populations before and after the introduction of enriched flour have demonstrated its beneficial effects. Clearly the contrast will be greatest when the population initially shows to a marked degree clinical symptoms of nutritional deficiencies. The classical investigation in this respect is the medical survey of Newfoundland made in 1944 by a group of experts. They showed that the population was in a poor nutritional state and suffering from diseases which could be ascribed to distinct nutritional deficiencies.[33] Steps were taken to improve its state, including the enrichment of its flour and bread. By 1948 the " total mortality fell from 12·1 to 10·5 per 1,000; the infant mortality in the city of St. John's declined from a level of 102 to 61 per 1,000 live births. Deaths from tuberculosis dropped about one fourth. Other factors probably contributed to these results; nevertheless there was a selective decrease in those signs of malnutrition which enrichment of bread and flour might be expected to repair, and in spite of considerable endeavour to increase the consumption of citrus fruits the

* See above, p. 140.

incidence of vitamin C deficiencies had not improved. The significance of enrichment as a major factor was confirmed by analyses of blood and urine."

In any discussion of enrichment it should be borne in mind that the investigations of McCance and Widdowson on German children immediately after the War * apparently showed that white bread, enriched even to American levels, had no demonstrable advantage over unenriched white bread. Until, however, the full details are published we cannot say whether, or how far, these findings conflict with the views expressed or summarised above.

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CHAPTER NINE

BREAD AND HEALTH

Bread in the British Diet

Since it is generally accepted that a high standard of nutrition plays an important part in the maintenance of health, it is clear that bread, being the staple article of food of the British and other western peoples, enters into considerations of health to a marked degree.

The normal extraction rate in the United Kingdom, under conditions of peace, is, as we have noted,* between 70% and 72%, the remaining 28–30% of the wheat being converted into animal feeding-stuffs. The proportion of the wheat that is fed to animals is, of course, not lost as food for man; it is returned in the form of milk, eggs and meat, which are essential not only for a palatable diet but also for a diet which is nutritionally adequate.† The advantages of a white flour with its greater quantity of wheat-feed, which, incidentally, is of higher feeding value than that obtained from the milling of a high-extraction flour, have always been stressed by agricultural interests. The problem received much attention early in the last War before the extraction rate was raised to 85%. Wright,[1] for example, calculated that increasing the extraction rate from 75% to 85% would only mean an increase of 3 Calories per man per day and a net loss in protein. In other calculations Bacharach [2] claimed that the change would bring an increase in vitamin B_1 and nicotinic acid, but a slight decrease in calories, protein, calcium and vitamins A and C. It is obviously impossible to arrive at a final conclusion; the figures taken for digestibility and the conversion factors for animals influence the results, and many of the nutrients in bread and animal products are so different that the two cannot be equated. From the national standpoint, too, there are the

* See above, p. 73. † See above, p. 145.

questions of the higher prices of animal products and the ability of the poorer classes to buy them.

A rate of extraction of 70–72% could not be maintained during either of the World Wars, when the strain on the United Kingdom's shipping resources made a reduction in her wheat imports vitally necessary. The loss of imported wheat was, on each occasion, made good in three ways: by enlarging the acreage under the plough within this country, by diluting the grist with wheat substitutes, and by raising the extraction rate of flour. In the 1914–18 War the third measure was accompanied by a marked deterioration in the quality and colour of the flour; the consequent gain in its nutritive value, although important, was incidental. In the 1939–45 War, by contrast, an effort was made to render the flour, and the bread and confectionery made from it, as attractive as possible to the consumer, whilst at the same time raising its nutritive value to the highest level possible. In war, even more than in peace, bread is our most important cereal food.

In the First World War the extraction rate began to rise in 1916, and reached a peak of 92% in March 1918; and much of this wheat flour was also diluted with other cereal flours, generally without adequate tests to find out to what extent additions would permit the making of satisfactory bread. In the Second World War a compulsory rate of 85% was not enforced by the Ministry of Food until March 1942. Between 1942 and 1945, after careful technical trials, wheat flour was diluted with a proportion, fluctuating between 0·1% and 10%, of oats, barley and rye.* In October 1944 the compulsory rate was reduced to 82·5%, and at the end of that year to 80%. The nutritional standard of the flour remained practically constant, however, since the millers had developed methods for the maximum incorporation of the scutellum fraction of the germ and of the endosperm attached to the bran. Research by the Research Association of British Flour-Millers had shown that these two fractions were the main sources of vitamin B_1, nicotinic acid and iron.

* See above, p. 61.

TABLE 1

Changes in the Extraction Rate and in the Admixture of Diluents, 1939–53

Extraction.	% of non-wheaten diluents.	Date.
70	—	Sept. 1939
73	—	Oct. 1939
75	—	Apr. 1941
85	—	Mar. 1942
85	5	Dec. 1942
85	10	Feb. 1943
85	7·5	Nov. 1943
85	5	Dec. 1943
85	2·5	Dec. 1943
85	—	Mar. 1944
82·5	—	Oct. 1944
80	—	Dec. 1944
82·5	—	Feb. 1946
85	—	Mar. 1946
90	—	May 1946
85	—	Sept. 1946
81	—	Aug. 1950–Aug. 1953

The opportunity was also taken during the last War to enforce a limited degree of enrichment with nutrients believed to be deficient in the diet as a whole. A project to enrich flour with synthetic vitamin B_1 was put into effect at the beginning of the War, but was superseded by the introduction of high-extraction milling.* However, in 1943 the enrichment of every 280 lb. sack of flour with 7 oz. of calcium became compulsory, and three years later this amount was doubled, with the result that the percentage of calcium supplied by bread to working-class diets increased from 5·9 in 1942 to 20·3 in 1943 and to 30·6 in 1947. A proportion of skimmed-milk powder was also added to flour between 1943 and 1944, but the amount available was too small to affect significantly the intake of animal protein or riboflavin.

Bread provided the foundation of the Government's nutrition policy during both World Wars. Rationing of bread was strenuously avoided, so that bread, together with

* See above, p. 160.

potatoes, would provide an unrestricted source of calories which guaranteed that nobody need go hungry, and, while satisfying the appetite, would supply most of the essential nutrients. The shortage of wheat occasioned by the Second World War continued for some years afterwards, owing to the requirements of countries stricken by the War and by famine, and in July 1946 rationing of flour and bread at last became unavoidable in the United Kingdom. However, the weekly ration allocated to each category of consumer, shown in Table 2, was so calculated as not to reduce the consumption of bread, but to prevent waste, and, with the other foods available, was sufficient to maintain the desirable calorie intake.

TABLE 2

British Bread Ration, 1946–48

	Oz. of bread (or flour).
Normal adults	63
Children under 4	35
Children 4–11	63
Adolescents 11–18	91
Expectant mothers	77
Women manual workers	77
Male manual workers	105

Rationing was brought to an end in July 1948, and two years later the extraction rate was lowered to 81%.* It was not, however, until 1953, when the industry was "freed" from Government control, that milling at the pre-war extraction rate was again permitted—but with the reservation that the flour must be enriched synthetically to bring its level of certain nutrients up to that of National 80%-extraction flour which the Post-War Loaf Conference (1945)[3] had considered to be nutritionally acceptable.

The importance of bread in the British diet during and after the Second World War, and the fact that (National) bread was something more than a source of energy, were brought

* Actually, about 10% of imported white flour was added to this 81%-extraction flour, bringing its overall extraction down to a figure slightly above 80%.

out clearly by the report on *Domestic Food Consumption and Expenditure* (1950) prepared by the Ministry of Food.[4] This survey covered 4,723 urban and rural households, which were carefully chosen to give a complete cross-section of the population of the United Kingdom. The households were further divided into the following social classes:

Class.	Gross income of head of household.
A	£13 a week or over
B	£8–£13 a week
C	£4 10*s*.–£8 a week
D	Less than £4 10*s*. a week

Specially trained women investigators were able to ascertain the consumption of food in each of these households and in turn to calculate its content of nutrients; details of the number, age, sex, etc., of the household were also recorded. The report gives detailed tables showing *inter alia* the contribution made by cereal products generally and by flour and bread in particular. The following figures for flour and bread are taken from these tables:

TABLE 3

Percentage of Total Daily Intake Supplied by Flour and Bread

Nutrient.	Social class.					
	A.	B.	C.	D.		
				Excluding old-age pensioners.	Old-age pensioners.	All Class D.
Energy	22	23·6	27·7	28·6	28·0	28·4
Protein	23·2	25·6	30·7	30·3	30·6	30·7
Calcium	18·7	21·7	27·0	28·4	26·2	27·9
Iron	23·5	26·0	29·9	31·3	32·5	31·6
B_1	30·9	33·7	37·6	39·5	38·5	39·0
Riboflavin	10·9	11·9	14·7	15·0	14·5	15·0
Nicotinic acid	21·7	23·3	26·9	26·6	27·5	26·8

The table shows not only the importance of flour and bread in the diet of the nation as a whole, but also their increased importance to the lower income groups. Bread is

the cheapest food; it is fortunate that it is such a valuable food.

Again, it is clear that the harder the work the more important bread becomes. Thus, during the war years 1942–45, when bread and flour supplied on the average 30·7% or 782 Calories out of the total daily intake of 2,550 Calories per head, Pyke [5] found that the daily intake of a group of shipyard workers was 3,372 Calories, out of which bread and flour supplied 1,198 or 35·5% of the total; in a group of steel roller-men with an intake of 4,143 Calories, bread supplied no less than 1,881 or 45·4% of the total.

The outstanding place of bread in the diet of man would seem to be confirmed by the work of McCance and Widdowson on the feeding of groups of German school-children on a diet in which different kinds of bread predominated and supplied the bulk (approximately 70%) of the calorie intake.* The health of the children over a period of one year was checked by tests made by expert medical observers. The results of the investigation have not been published in detail but brief reports [6] indicate that the children's health was excellent in every way.

Bread and Obesity

A discussion on the causes and treatment of obesity might be considered to be outside the scope of this book, but as the question of bread in relation to this subject has been so frequently raised, the following remarks may be appropriate.

The majority of cases of over-weight are due to food intake exceeding the body's requirements. It has been seen † that excess carbohydrate in the diet is stored as fat, and the same is true of excess fat. The chief exception appears to be protein, which can be eaten *ad lib.* by most people without any increase in weight. An excessive intake of bread, like that of any other food of high carbohydrate content, may lead to obesity, but in most people the appetite is a fairly accurate guide to the food requirements.

The treatment of obesity, with the exception of the rare

* See above, p. 149. † See above, p. 115.

forms associated with changes in the endocrine system of the body, is to reduce the food calorie intake below requirements. The excess fat is then withdrawn from the fat depots, and utilised as a source of energy, thus augmenting the food intake. The reduction of the input can be effected either by complete starvation or by modifying the diet, so that the calorie content is reduced to something in the region of 1,000 Calories per twenty-four hours. If the daily requirements are 2,500 Calories per day and the food intake only 1,000 Calories, the patient must lose weight.

As an alternative, the food calorie intake may be kept constant, at, say, 2,500 Calories per day, and the requirements increased to, say, 3,500 Calories per day by taking exercise. Table 4 shows the large amount of exercise required to achieve this.[7] Unfortunately, this method is seldom successful, because in many people exercise increases the appetite.

TABLE 4

Calorie Requirements in Certain Forms of Exercise

Exercise.	Calories per hour.
Washing dishes	59
Walking	130–240
Walking very fast . . .	565
Cycling	180–600
Rowing	120–600
Swimming	200–700
Sawing wood	390
Running	500–1,000

It has been known for a considerable time that specific reductions in certain of the basic foods are more effective than mere non-specific reduction of total calories. A "reducing" diet will be more effective if it contains an excess of protein, which not only is not stored but increases the food requirements by the so-called specific dynamic action. Recently, Kekwick and Pawan (1953)[8] have shown that, next to protein, a high fat diet is attended with the greatest loss of weight, whereas carbohydrate, if used in a reducing diet, causes the least loss of weight.

Bread may be included in a weight-reducing diet, but the quantity taken must be controlled. Starch, dextrins and sugars are all carbohydrates and the breaking down of bread starch to dextrins does not alter its calorific value. A high protein bread is an advantage.

Bread and Dental Caries

Let us now look at some of the diseases in the prevention and treatment of which bread plays, or is believed to play, a part. An outstanding one is *dental caries*, a very widespread disease. There is a vast and confused literature on this subject, and any attempt to summarise it can at best give only one point of view. It seems reasonably certain, however, that diet is the determining factor in the root structure and calcification of the tooth. The work of Lady Mellanby [9] is classical in this field. From her experiments on dogs and other animals she has shown that dietary factors, notably an adequacy of vitamin D and calcium, are of the first importance to sound teeth. From these she has, by surveys of a very large number of human teeth, developed the theory that the better the tooth structure the less susceptible it is to caries. This appears to be a logical deduction, and despite apparent anomalies it is generally accepted. On the actual cause of caries there are several schools of thought, including (i) that it is due to the action of micro-organisms and their enzymes on carbohydrate, which produces an acid medium, which in turn decalcifies the enamel and exposes the organic matrix of the enamel and underlying denture to the further action of proteolytic enzymes; (ii) that it occurs only in indents or "food traps" on the surface of the teeth, so that smooth teeth should show no caries; (iii) that it is caused by too much sugar in the diet; (iv) that it is due to the "pappy" nature of our food and consequent under-function of our teeth, jaws and masticatory muscles (raw or coarser food, the latter including bread made from high-extraction flour, reduces the incidence of caries); and (v) that it is due to an inadequate intake of vitamin C.

Recent work favours the first of these schools—the fermentation theory of dental caries—and in fact most workers agree that the immediate agent in the production of caries is the acid produced in the vicinity of the teeth by bacteria. Fosdick (1953) [10] holds the view that the acid is produced in the presence of sugar only, and not of starch. Differences in opinion arise over the importance to be attached to other factors. At the present time, considerable thought is being given, both in the U.S.A. and in this country, to the fluoridation of drinking-water in order to reduce caries. Some workers hold that this step would reduce caries by lowering the solubility of the enamel. It should be remembered, however, that fluorine is an extremely powerful enzyme poison.

Whenever dental caries is under discussion, bread, as a factor in its production, is usually introduced. The extraction rate, mineral and vitamin content of the bread, the specific action of gluten, the flour improvers used, and the existence of anti-bodies or protection factors in flour, have all been named, but so far bread as such has not been shown to play a part either in promoting, or in inhibiting, dental caries, except as a source of carbohydrate. Much further work is required. It would seem, for example, that as a first step the teeth of suitable experimental animals through several generations should be examined. The diets would have to be standardised and, apart from the controls, be marginal or deficient in one or more of the established accessory factors. In these diets the bread would be a further variable, in that it would be baked from flours of different extraction, granularity, etc. Statistical analysis, both of the size and plan of the experiment, and of the results, would of course be essential. The labour and experimental work would be considerable, but this type of experiment might help at least to give the problem of dental caries some definition. It is doubtful if mere surveys, valuable as they have been in the past, will bring us to a clear understanding and in turn a solution of the problem.

Bread and Rickets

Allied to dental caries is *rickets*, in the aetiology of which bread has figured largely, mainly through the work of Mellanby. Mellanby found in his early experiments with puppies [11] that the more bread they ate the greater was the tendency for them to develop rickets. The degree of rickets was greatest in those eating brown bread and least in those eating white bread; oatmeal was considerably more rachitogenic than wheaten flour of whatever extraction. Harrison and Mellanby [12] found that the anti-calcifying substance in cereals was phytic acid, which, as we have seen,* is greatest in wholemeal flour and diminishes as the extraction falls. This effect of phytic acid can be offset by the addition of a suitable amount of a calcium salt, even to wholemeal flour.

The protective factors against rickets are vitamin D and calcium, which also make for sounder teeth and a reduced tendency to caries. Cowell, in a review of the published work on the relation of dental caries to rickets,[13] showed that there is a distinct relationship between rickets and hypoplasia of the teeth, and most observers, including a Committee of the Medical Research Council,[14] have found that gross hypoplasia is associated with an increased incidence of dental caries.

The key to the elimination of rickets and to at least a considerable reduction in dental caries is an overall improvement in the diet, which must contain all the known nutritional factors and in those amounts known to be compatible with good health.

Bread and Diseases of the Digestive Tract

Chronic constipation is generally believed to be alleviated by the roughage in wholemeal bread or brown bread. The extra fibre in such bread tends to make the contents of the colon more bulky and also softer, whilst the extra amount of vitamin B_1 present helps to maintain neuro-muscular tone. It is widely

* See above, p. 56.

held that the decline in the sale of purgative drugs in this country during the Second World War was due to the fact that the people were, as a whole, less constipated as the result of the raised extraction of flour. On the other hand, it must not be overlooked that the roughage from the increased consumption of potatoes and vegetables to make good the shortage of meat, eggs, butter and fruit may also have contributed. McCance and his associates (1953),[15] moreover, have shown by X-ray examination, using a small quantity of barium sulphate in the bread, that brown bread not only causes a greater secretion of digestive juices and a greater bulk of fæces, but also passes more rapidly through the digestive tract than white bread.

The consumption of 80–85%-extraction flour during the war years also brought out a new fact regarding its effects on certain ulcerative states, such as *peptic ulcer.* It was decided by the Special Diets Committee of the Medical Research Council [16] that this flour, far from being harmful in such complaints, did in fact hasten the healing process. It was the declared view of the Committee that 80–85%-extraction flour harmed no one suffering from any disease. This view does, however, prompt us to refer to one disease in which it has now been established that wheaten bread is contra-indicated. Frazer and his colleagues [17] have shown that the relatively rare *cœliac disease* * is aggravated by wheat gluten, and that the removal of wheat flour from the diet of the patients results in a rapid improvement of their condition.

* Cœliac disease occurs mainly in children and is characterised by lack of appetite, little gain in weight, abdominal distension, and fatty diarrhœa.

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CONCLUSIONS

What are the conclusions to be drawn from this book? The first is, perhaps, that bread is not only our most important foodstuff but also an exceedingly complicated foodstuff. It supplies about one-quarter of our energy requirements and more protein than any other single food, and it is a rich source of the B vitamins and of many minerals, including iron. It may also supply factors not yet identified which are necessary to health; the wheat grain is a storehouse of many nutrients, both known and unknown.

Much of the published work on the nutritional value of wheat, flour and bread has been divorced from practice. In general, it has tended to examine bread "in a vacuum", instead of regarding it as merely one item in our diet. Experiments on rats, given only a bread diet, cannot tell us which is the best bread for man to eat. Even the diet of the very poor contains other foods which undoubtedly supplement or enhance the food value of bread. The food value of a heterogeneous mixture of amino-acids, and possibly to some extent of nutritional factors generally, is not a matter of simple arithmetic; certainly the quantitative interactions between amino-acids in their effects on growth and maintenance are still largely a virgin field of enquiry.

Stress has been laid by Governments and by Nutritional Committees on the importance of minimum levels of nutrients in bread; and we welcome the decision of our own Ministry of Food that white flour and bread in this country should be enriched up to a standard level. In the present state of our knowledge such a standard is essential in any system of nutritional planning. It is intended to safeguard the health and well being of the poorer sections of the community. For other sections, it is probably true to say that the type of bread eaten is of much less consequence.

Finally, since bread is eaten at nearly every meal over the greater part of the life-span, it must be palatable and

generally acceptable—but it must also be wholesome in the strict sense of the word. For this reason we welcome the present investigations into the addition of chemicals to food, including the use of chemical improvers in bread. Their outcome should be to provide additional safeguards for our health.

Above all, we would emphasise the necessity for still further research, both pure and applied, on wheat, flour and bread, in the scientific, nutritional and medical fields.

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